

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

PB-291 000

Indoor Air Pollution in the Residential Environment
Volume II. Field Monitoring Protocol, Indoor Episodic
Pollutant Release Experiments and Numerical Analyses

Geomet, Inc., Gaithersburg, MD

Prepared for

Department of Housing and Urban Development, Washington, DC

Dec 78

**HUD
EPA**

United States
Department of Housing
and Urban Development

Office of Policy Development and Research
Office of Community Planning and Development
Washington DC 20410

United States
Environmental Protection
Agency

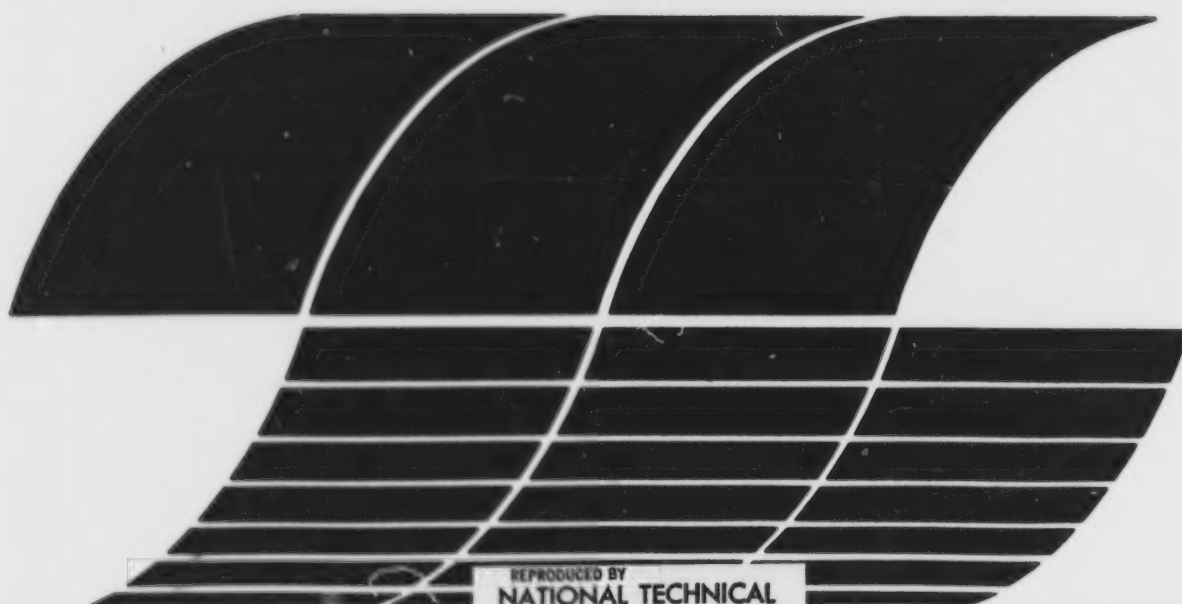
Environmental Monitoring and Support
Laboratory
Research Triangle Park NC 27711

EPA-600/7-78-229b
December 1978

PB 291000

**Indoor Air Pollution in the
Residential Environment
Volume II
Field Monitoring Protocol,
Indoor Episodic Pollutant Release
Experiments and Numerical
Analyses**

**Interagency
Energy/Environment
R&D Program Report**



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SPRINGFIELD, VA. 22161

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TECHNICAL REPORT DATA		
(Please read instructions on the reverse before completing)		
1. REPORT NO. EPA-600/7-78-229b	2.	3. REPORT'S ACCESSION NO. PB291000
4. TITLE AND SUBTITLE INDOOR AIR POLLUTION IN THE RESIDENTIAL ENVIRONMENT Volume II - Field Monitoring Protocol, Indoor Episodic Pollutant Release Experiments and Numerical Analyses	5. REPORT DATE December 1978	
	6. PERFORMING ORGANIZATION CODE	
7. AUTHOR(S) Demetrios J. Moschandreas (Editor)	8. PERFORMING ORGANIZATION REPORT NO. GEOMET Report Number EF-688	
9. PERFORMING ORGANIZATION NAME AND ADDRESS GEOMET, Incorporated 15 Firstfield Road Gaithersburg, Maryland 20760	10. PROGRAM ELEMENT NO.	
	11. CONTRACT/GRANT NO. 68-02-2294	
12. SPONSORING AGENCY NAME AND ADDRESS U.S. F.P.A. Environmental Research Center Research Triangle Park, North Carolina and	13. TYPE OF REPORT AND PERIOD COVERED Final Report	
U.S. Dept. of Housing and Urban Development Office of Policy Development and Research	14. SPONSORING AGENCY CODE	
15. SUPPLEMENTARY NOTES		
16. ABSTRACT This second volume of the two-volume series on "Indoor Air Pollution in the Residential Environment" contains three chapters. Chapter 1 describes the experimental monitoring design for obtaining continuous and intermittent air samples under "real-life" conditions. The site selection criteria, monitoring techniques, data management system and quality assurance program are discussed in detail. Chapter 2 refers to specific experiments of episodic contaminant release in the indoor residential environment. The monitoring technique, developed by ITRI, and the data obtained are presented in this section. Finally, in Chapter 3 numerical techniques used to determine the sensitivity coefficients of the GEOMET Indoor-Outdoor Air Pollution (GIOAP) model, see Volume I, are detailed.		
17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Residential Air Quality Monitoring Residential Site Selection Criteria Monitoring Techniques Data Management System Quality Assurance Program Instantaneous Pollutant Release Sensitivity Coefficients	Air Pollution Monitoring Numerical Techniques	
18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 244
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE A11-H \$1

EPA-600/7-78-229b
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and Urban Development
Office of Policy Development and Research
Washington, DC 20410

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Environmental Monitoring and Support Laboratory
Research Triangle Park, North Carolina 27711

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Chapter 1

INDOOR AIR POLLUTION ASSESSMENT, CONTROL AND HEALTH EFFECTS

Section 1

BACKGROUND

This 24-mo project has been designed as a program of research intended to produce new data and insights concerning the occurrence, behavior, and significance of air pollution in nonworkplace, indoor environments through observation, evaluation, and analysis of 46 weeks of monitoring data. The project has six specific objectives:

1. To identify the indoor and outdoor pollution sources that affect indoor air quality.
2. To determine the relative magnitude and concentration of the pollutants from these sources in the indoor environment.
3. To assess the potential or actual health and welfare effects of these pollutants upon occupants of indoor structures.
4. To determine the impact and assess the importance of energy conservation measures (as applied to existing and new structures) upon the generation, buildup, and elimination of indoor air pollutants.
5. To identify various control techniques that could be utilized to reduce the concentration and effects of indoor air contaminants for the protection of public health and welfare.
6. To suggest basic alternative techniques or energy conservation measures that would reduce or eliminate unacceptable levels of indoor air contaminants.

These six aspects of the project are linked in a broad objective of optimizing the energy conservation/air quality/health relationships in indoor spaces through identification

of causal relations and identification of feasible points of intervention.

The scope of contract effort has the following principal elements:

Phase I - A 4-mo literature search and appraisal of the state of current knowledge about indoor air pollution, including its occurrence, its behavior, its health effects, its relationship to energy conservation measures, and methods for its control. This work culminates in a Phase I report.

Phase II - A 24-mo effort (beginning simultaneously with Phase I) to perform the following work:

- ° A program of field monitoring for indoor and outdoor pollutants, meteorology, energy factors, building occupancy, and building characteristics to be conducted for at least 46 weeks of continuous measurements in three experimental dwellings, four conventional dwellings, one school, six Hi/Lo Rise apartments, two mobile homes, and a hospital.
- ° An empirical analysis of the relationships between indoor air pollution concentrations and various pollution control systems, based upon data from the field monitoring program.
- ° The development of a general mathematical model (or group of models) capable of predicting indoor air pollution concentrations as a function of independent variables, among which are outdoor quality; meteorology; building design, occupancy, and usage; and energy conservation measures.

The Phase II effort will result in a separate Final Report of project work.

The data to be gathered, the analyses to be made, and the models to be developed are to be of general value for the setting of future research and regulatory policies with respect

to indoor air quality. They must also be of particular value for the design and execution of a later Phase III program (not a part of the present project) which has been conceived as an 18-mo prospective epidemiological study of the health effects of indoor air pollution, using both monitored and modeled data.

The work of Phases I and II is being undertaken by a multidisciplinary project team directed by GEOMET, Incorporated, which provides management as well as the health effects, air quality analysis, and modeling aspects of the technical program. GEOMET is assisted by the efforts of two subcontractors; Hittman Associates, Inc., for energy considerations, and PEDCo-Environmental Specialists, Inc., for field monitoring. This document presents the Field Monitoring Protocol.

° The Mobile Shelter

PEDCo engineers, who are experienced in mechanical systems design, explored and evaluated a number of shelter/trailer types and have chosen a 24-ft, commercially produced, "Wells Cargo" trailer (Wells Cargo, Inc., Elkhart, Ind.). Features of this unit include:

- ° Superior quality (aircraft grade) aluminum alloy shell.
- ° All welded construction, reinforced metal chassis.
- ° The chassis and running gear 1) reduce road vibration and shock to a level equal to or less than that which would be received by passengers in a standard American automobile, regardless of road conditions, and 2) when parked, provide a rigid and stable floor, and a means for attaining a level floor, regardless of terrain.

Based on heating/cooling analyses and experience with similar systems in the field, provisions to maintain temperatures for human comfort and equipment safety within $\pm 1.6^{\circ}\text{C}$ ($\pm 3^{\circ}\text{F}$) during all weather conditions is provided. The high thermal efficiency of the shelter panel design enables selection of a low capacity and consequently low power consumption Environmental Control System (ECS). The ECS is comprised of a compressor/condenser unit, a heating unit, an air handler, and an automatic heating/cooling thermostatic control. The ECS will provide 15,500 Btu/h heating and 18,000 Btu/h cooling which are ample capacities for maintaining $21 \pm 1.6^{\circ}\text{C}$ ($70 \pm 3^{\circ}\text{F}$) internal temperature under the most extreme environmental conditions.

The metal outer shell and doors offer excellent protection from vandalism. Outside equipment, such as the roof access ladder and meteorological tower, will be fitted with covers to discourage children or others from climbing on the shelter. In order to provide security in case of electrical storms, lightning protection devices have been installed to prevent damage to the system.

A conceptualized section view of the shelter system is presented in Figure 1. Layout of the instrumentation and support facilities is shown in Figure 2. A humidity chamber (equilibration chamber) has been built into the trailer so that particulate filters may be weighed at constant humidity.

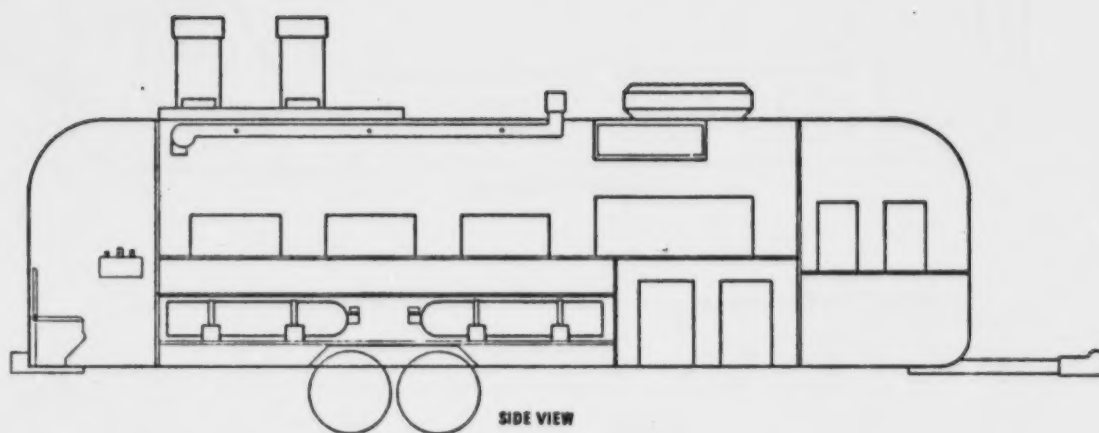


Figure 1. Sectional view of the sampling shelter system.

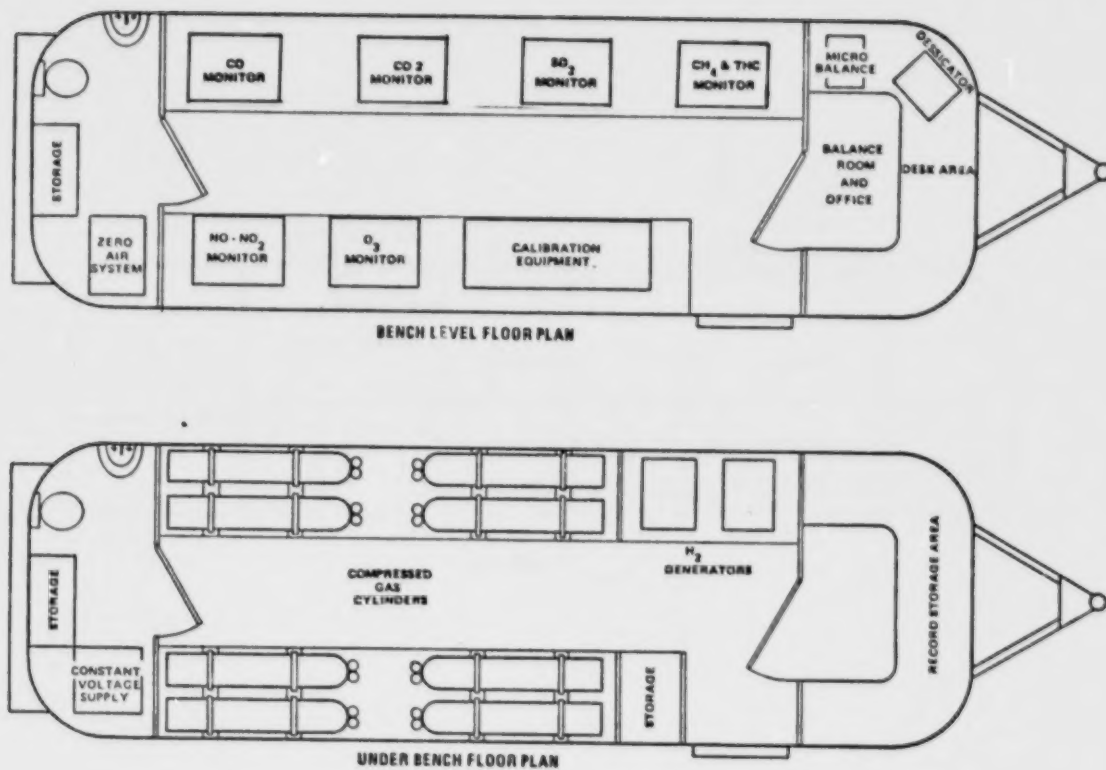


Figure 2. Floor plan of the sampling shelter system.

Since the mobile unit will be moved from site-to-site throughout this project (see schedule in Section 2), a "check-list" document has been prepared to insure proper preparation of the system prior to each transit. Reference Document No. 3252-004, titled "Preparation of Mobile Laboratory for Transit" is attached (Figure 3).

A second general reference document prepared to assist the field operators, Reference Document No. 3252-003, "Daily Operational Checklist," is also included in this section (Figure 4).

PREPARING MOBILE LABORATORY FOR TRANSIT

1. Check tower hold down mounts and also bolts on front of tower. _____
2. Check electric service hold down clamp. _____
3. Close bathroom vent. _____
4. Remove fire extinguisher and place on floor level. _____
5. Check all cylinder hold downs and insert lock pins. _____
6. Tape overhead lites. _____
7. Check all overhead cabinets for loose gear. _____
8. Store all loose supplies. _____
9. Remove pans from auto balance and place the unit on floor level within foam padded box. _____
10. Remove ink from wind speed unit. _____
11. Remove barometer from wall and store properly. _____
12. Remove drawers from front table and place on the floor. _____
13. Remove the water container from bathroom. _____
14. Check all bolts and nuts on air ride system. _____
15. Close and lock file cabinets. _____
16. Check units with pullout electronics (GC, THC, CO, CO₂), short their meters with shorting clip. _____
17. Check that all instruments are securely strapped down and foam rubber is placed under each instrument. _____

Doc. Ref. No. 3252-004
June 1976

Figure 3. "Preparing mobile laboratory for transit" document.

18. Tape refrigerator door and front overhead cabinets. _____
19. Remove all recorders from their rack and place on foam rubber in front office of trailer. _____
20. Remove MSA THC-CH₄ Analyzer and place in rear of truck on 4" of foam rubber. _____
21. Secure the four extra zero air cylinders on rear floor of trailer, use polyfoam between each cylinder. _____
22. Inflate air ride system to provide a medium firm ride -- Caution: Do not over-inflate air bags. _____
23. Lock trailer doors. _____
24. Check that hitch is locked onto ball. _____
25. Place torsion bars in 4th chain link. _____
26. Check turn signals, brake lights, and driving lights. _____

Figure 3 (Continued)

DAILY OPERATIONAL CHECKLIST

DATE _____ OPERATOR _____

LOCATION _____ ARRIVAL TIME _____

1. Physical outside inspection remarks. _____

2. Start 0600 Bubbler sample _____

3. Electric clock time _____

4. Battery clock time _____

5. Electric service status _____

Remarks: _____

6. Check operational status of each monitor and recorder: _____

Remarks:

Hydrocarbon _____

CH₄ _____

H₂ Generator _____

SO₂ _____

O₃ _____

NO_x _____

CO₂ _____

CO _____

Pumps _____

Doc. Ref. No. 3252-003
June 1976

Figure 4. "Daily operational checklist" document.

7. Stamp and time sync recorders. _____
Record adjustments in instrument logs.
8. Check chart paper supply of each recorder. _____
9. Check and record cylinder pressures in log book. _____
10. Switch programmer to calibrate mode and zero all monitors for five minutes. _____
11. Record unadjusted zero values in instrument logs. _____
12. Adjust zero and record adjustment in instrument logs. _____
13. List monitors requiring more than +1% adjustment: _____

14. Span all monitors for five minutes and record unadjusted values in instrument logs. _____
15. List those monitors which are off by more than +2% of their calculated value: _____

16. Adjust span values on those monitors which are less than +2% of their calculated value. Record adjustment in instrument log. _____
17. Return programmer to sample. _____
18. Dynamically calibrate those monitors which are in excess of +1% of zero and/or +2% of span. Note in instrument log. _____
19. Cut and file strip charts from midnight to midnight. Reduce data as time permits. _____
20. Turn off particulate samplers and record data. (24-hour samples - noon to noon). _____

Figure 4. (Continued)

21. Change particulate filters _____
22. Change aldehyde bubblers per following
 sampling schedule: #1 6 a.m. - 10 a.m. _____
 #2 10 a.m. - 2 p.m. _____
 #3 4 p.m. - 8 p.m. _____
- Record data.
23. Change charcoal absorption tubes every
 24-hours (noon to noon) and record data. _____
24. Change dichotomous samplers. _____
25. Check power recorders. _____
26. Check streaker samplers. _____
27. Check and record in logbook door open/close
 counter. _____
28. Check operation of the four hydro-thermographs _____
29. Check oil level in the five pumps _____
30. Check daily home occupant's log for complete-
 ness _____
31. Stamp and time sync all recorders before
 leaving trailer. Record adjustments in
 instrument logs. _____
32. Make final visual inspection of all samplers,
 recorders, and pumps. _____
33. Turn off all lights, confirm operations of
 heating/air-conditioning system, lock both
 doors. _____

Figure 4. (Continued)

Section 2

SITE SELECTION

Hittman Associates, Inc. initially selected several structures of both conventional and experimental design that appeared compatible with the objectives of the study. PEDCo then conducted a presurvey to determine possible physical constraints; for example, the site must have allowed placement of the mobile laboratory very near the structure to be monitored. When the most desirable structures had been selected, a representative of the PEDCo staff interviewed each property owner, explaining the objectives of the study in layman's terminology. During this meeting, PEDCo could observe the interior of the structure, the lifestyle and number of occupants, and any other factors that could bias the collection of valid data, such as abnormally poor housekeeping practices or smoking habits of the residents. In the event that the house and its occupants met the general criteria for the project objectives and they were willing to participate in the study, PEDCo provided the owner/apartment dweller with an "Agreement to Use Property," as shown in Figure 5, and a monitoring schedule, as presented in Figure 6.

AGREEMENT TO USE PROPERTY

This is an agreement between PEDCo-Environmental Specialists, Inc. (referred to as PEDCo), an Ohio Corporation, and _____ (Mr. Homeowner) _____ (referred to as the Owner), entered into this _____ (day) day of _____ (month), 1976.

First: PEDCo as a subcontractor for the U.S. Environmental Protection Agency is collecting scientific data regarding indoor ambient air quality.

Second: Owner currently owns and is in possession of a building located at _____ (Appropriate Address) _____ (referred to below as the Building).

In consideration of the mutual covenants and promises set forth below, PEDCo and the Owner agree as follows:

1. PEDCo may set up and operate on the Building property an ambient air monitoring system to measure air quality in the Building. The system shall consist of a trailer located adjacent to the Building, for housing certain instrumentation, and a network of conduits between said trailer and certain rooms within the Building. Additionally, particulate and gas sampling equipment and energy metering devices shall be permitted temporary installation in the Building. PEDCo shall be permitted vehicular access to the trailer as required for its installation, maintenance, operation, and removal.
2. PEDCo personnel shall be given access to the Building in accordance with the schedule attached hereto.
3. PEDCo will bear all expenses of installing, operating, and removing the monitoring system.

Figure 5. "Agreement to use property" document.

4. PEDCo shall pay the Owner a total of \$ _____, payable as follows:
 - a) \$ _____ prior to installation of the monitoring system.
 - b) \$ _____ within 10 days after termination of this agreement or within 10 days following termination of all on-site sampling, whichever comes first.
5. The term of this agreement is (month/day), 1976 to (As required), 1977.
6. At the termination of this agreement the air monitoring system and all equipment related thereto will be removed and the property restored to its original condition at no expense to the Owner.

IN WITNESS WHEREOF, the parties have caused this agreement to be entered as of the day first above written.

PEDCo-ENVIRONMENTAL SPECIALISTS, INC.

By _____

Owner _____

Figure 5. (Continued)

° SCHEDULE °

PEDCo will conduct a two-phase sampling program. Based on best estimates, PEDCo equipment and personnel will be on-site (on Building property) for approximately eighteen (18) days during the following periods: _____, 1976; _____, 1977.

During these periods, PEDCo personnel shall be allowed access to the Building as follows:

1. As required during a three (3) day period prior to the initiation of active sampling in order to install a network of sampling lines (conduits) between the trailer and three (3) rooms in the Building. Sampling access to and in these three rooms shall be approved by the Owner. However, it is required that one (1) of these rooms shall be the kitchen of the Building. PEDCo will exercise all possible care in locating interior sampling lines so as to cause minimal interference with the Owner's activities and to protect occupant safety.
2. On two (2) occasions during each day of a subsequent fourteen (14) day period of active sampling in order to collect and replace sample media and to inspect and verify proper operation of the temporarily-installed indoor monitors. It is required that one (1) of these occasions be the same time each day in order to allow collection of 24-hour samples.
3. On twelve (12) successive one-hour intervals of approximately fifteen (15) minutes each, on three (3) days during the above noted fourteen (14) day period in order to monitor Building ventilation characteristics using "tracer" techniques.
4. As required during a one (1) day period following termination of active sampling in order to remove all sampling lines, temporarily-installed indoor monitors, and return the premises to their original condition.

The above conditions are based on expected cooperation between the Owner and PEDCo and recognize that specific dates and times required for implementation of this schedule must be mutually arranged when the air monitoring system arrives on-site.

Figure 5. (Continued)

AGREEMENT TO USE PROPERTY
(APARTMENT AGREEMENT)

This is an agreement between PEDCo-Environmental Specialists, Inc. (herein called PEDCo), an Ohio Corporation, located at 11499 Chester Road, Cincinnati, Ohio, and (Apartment dweller), (herein called Tenant), entered into this ____ day of _____, 1977.

First: PEDCo as a subcontractor for the U.S. Environmental Protection Agency is collecting scientific data regarding indoor ambient air quality.

Second: Tenant currently leases and is in possession of Apartment No. ____ located at _____ (referred to below as Apartment).

In consideration of the mutual covenants and promises set forth below, PEDCo and Tenant agree as follows:

1. PEDCo may set up and operate in the Apartment an ambient air monitoring system to measure air quality in the Apartment. The system shall consist of a network of conduits running into the Apartment from a trailer located adjacent to the building in which the Apartment is located. Additionally, particulate and gas sampling equipment and energy metering devices shall be permitted temporary installation in the Apartment.
2. PEDCo personnel shall be given access to the Apartment in accordance with the schedule attached hereto.
3. PEDCo will bear all expenses of installing, operating, and removing the monitoring system.

Figure 5. (Continued)

4. PEDCo shall pay the Tenant a total of \$_____, payable as follows:
- a) \$_____ prior to installation of the monitoring system.
 - b) \$_____ within 10 days after termination of this agreement or within 10 days following termination of all on-site sampling, whichever comes first.
5. The term of this agreement is _____, 1977, to _____, 1977.
6. At the termination of this agreement the air monitoring system and all equipment related thereto will be removed and the property restored to its original condition at no expense to the Tenant.

IN WITNESS WHEREOF, the parties have caused this agreement to be entered as of the day first above written.

PEDCo-ENVIRONMENTAL SPECIALISTS, INC.

By _____

Tenant _____

Figure 5. (Continued)

° SCHEDULE °

PEDCo will conduct a single-phase sampling program. Based on best estimates, PEDCo equipment and personnel will be on-site (on Building property) for approximately eighteen (18) days during the following period: _____ to _____.

During these periods, PEDCo personnel shall be allowed access to the Building as follows:

1. As required during a three (3) day period prior to the initiation of active sampling in order to install a network of sampling lines (conduits) between the trailer and three (3) rooms in the Building. Sampling access to and in these three rooms shall be approved by the Owner. However, it is required that one (1) of these rooms shall be the kitchen of the Building. PEDCo will exercise all possible care in locating interior sampling lines so as to cause minimal interference with the Owner's activities and to protect occupant safety.
2. On two (2) occasions during each day of a subsequent fourteen (14) day period of active sampling in order to collect and replace sample media and to inspect and verify proper operation of the temporarily-installed indoor monitors. It is required that one (1) of these occasions be the same time each day in order to allow collection of 24-hour samples.
3. On twelve (12) successive one-hour intervals of approximately fifteen (15) minutes each, on three (3) days during the above noted fourteen (14) day period in order to monitor Building ventilation characteristics using "tracer" techniques.
4. As required during a one (1) day period following termination of active sampling in order to remove all sampling lines, temporarily-installed indoor monitors, and return the premises to their original condition.

The above conditions are based on expected cooperation between the Owner and PEDCo and recognize that specific dates and times required for implementation of this schedule must be mutually arranged when the air monitoring system arrives on-site.

Figure 5. (Continued)

FIELD MONITORING SCHEDULE
1976-1978

Location	Set Up	Start Monitoring	Finish Monitoring and Calibration	Move and General Maintenance
Washington Conv Hse		7/2/76	7/18/76	
Washington Exp Hse		7/25/76	8/9/76	
Baltimore Exp Hse		8/12/76	8/25/76	
Baltimore Conv Hse		8/28/76	9/11/76	
Denver Conv Hse		9/29/76	10/14/76	
Denver School		10/21/76	11/8/76	
Denver Jewish Hosp		11/10/76	11/14/76	
Chicago Conv Hse		11/18/76	12/3/76	
Chicago Exp Hse		12/6/76	12/20/76	12/21/76 thru 1/2/77
Baltimore Exp Hse	1/3/77	1/4/77	1/20/77	1/20/77
Baltimore Conv Hse	1/21/77	1/21/77	2/4/77	2/5/77 thru 2/6/77
Pittsburgh Mobile Home #1	2/7/77	2/8/77	2/23/77	2/24/77
Pittsburgh Mobile Home #2	2/24/77	2/25/77	3/13/77	3/14/77 thru 3/16/77
Pittsburgh Lo-Rise Apt #1	3/17/77	3/18/77	4/1/77	--
Pittsburgh Lo-Rise Apt #2	4/1/77	4/2/77	4/17/77	--
Pittsburgh Lo-Rise Apt #3	4/17/77	4/18/77	5/2/77	5/3/77 thru 5/7/77
Pittsburgh Hi-Rise Apt #1	5/8/77	5/9/77	5/23/77	--
Pittsburgh Hi-Rise Apt #2	5/24/77	5/25/77	6/9/77	--
Pittsburgh Hi-Rise Apt #3	6/10/77	6/11/77	6/25/77	6/26/77 thru 7/11/77
Chicago Exp Hse	7/12/77	7/13/77	7/27/77	7/27/77
Chicago Conv Hse	7/28/77	7/28/77	8/5/77	8/6/77 thru 8/8/77
Washington Conv Hse	12/6/77	12/7/77	12/21/77	12/22/77
Washington Exp Hse	1/10/78	1/11/78	1/25/78	1/26/78 thru 1/31/78

Figure 6. Monitoring schedule.

The occupants were required to schedule their activities, such as vacation trips, so as to not to conflict with the monitoring schedule. It was important that activities within the home during the monitoring period were typical of normal family routine.

After the property use agreement was executed, PEDCo performed the necessary logistics, arranging for power requirements with the local utility company and a certified electrical contractor.

SITE DESCRIPTIONS

For each sampling location selected, PEDCo prepared a description of the site. Each site description included as a minimum, but is not limited to, the following information:

- ° Address of the structure
- ° Structure type
- ° Size of family within dwelling
- ° General information pertaining to heating, air conditioning, cooking facilities, and other energy-related parameters
- ° Photograph of residence
- ° Geographical sketch of the structure location with respect to the urban area in the vicinity
- ° Floor plan of the structure showing the location of the sampling probes.

Site descriptions for the selected sampling locations are given in the following pages.

Washington Conventional, Detached

° Silver Spring, Maryland

During the first monitoring session, occupants of this dwelling consisted of four adults: husband, wife, son, and full-time maid. The maid does not sleep at the residence but is present 5 d per week. The residence is a tri-level brick dwelling without storm windows, is heated with a gas forced-air furnace, and is equipped with conventional electric air conditioning. Figure 7 is a photograph of the residence. This residence is located very close to the Capital Beltway, as shown in the sketch presented in Figure 8. Location of the sampling probes in the kitchen, master bedroom, and living room is shown in Figure 9.

During the second monitoring period, the occupants of this residence consisted of two working women. One worked at a full-time job away from the residence, while the other ran an office located within the home. The structure type and facilities within remained unchanged. However, the location of two sampling probes were changed to the dining room and bedroom 1.

Washington Experimental, Detached

° Silver Spring, Maryland

This family consists of four adults: husband, wife, and two teenage children. The residence is a two-story brick home utilizing a solar panel system for heating, supplemented by an oil-fired boiler as required. The house also has central air conditioning, which is used only during periods



Figure 7. Photograph of the Washington, D.C., conventional house.

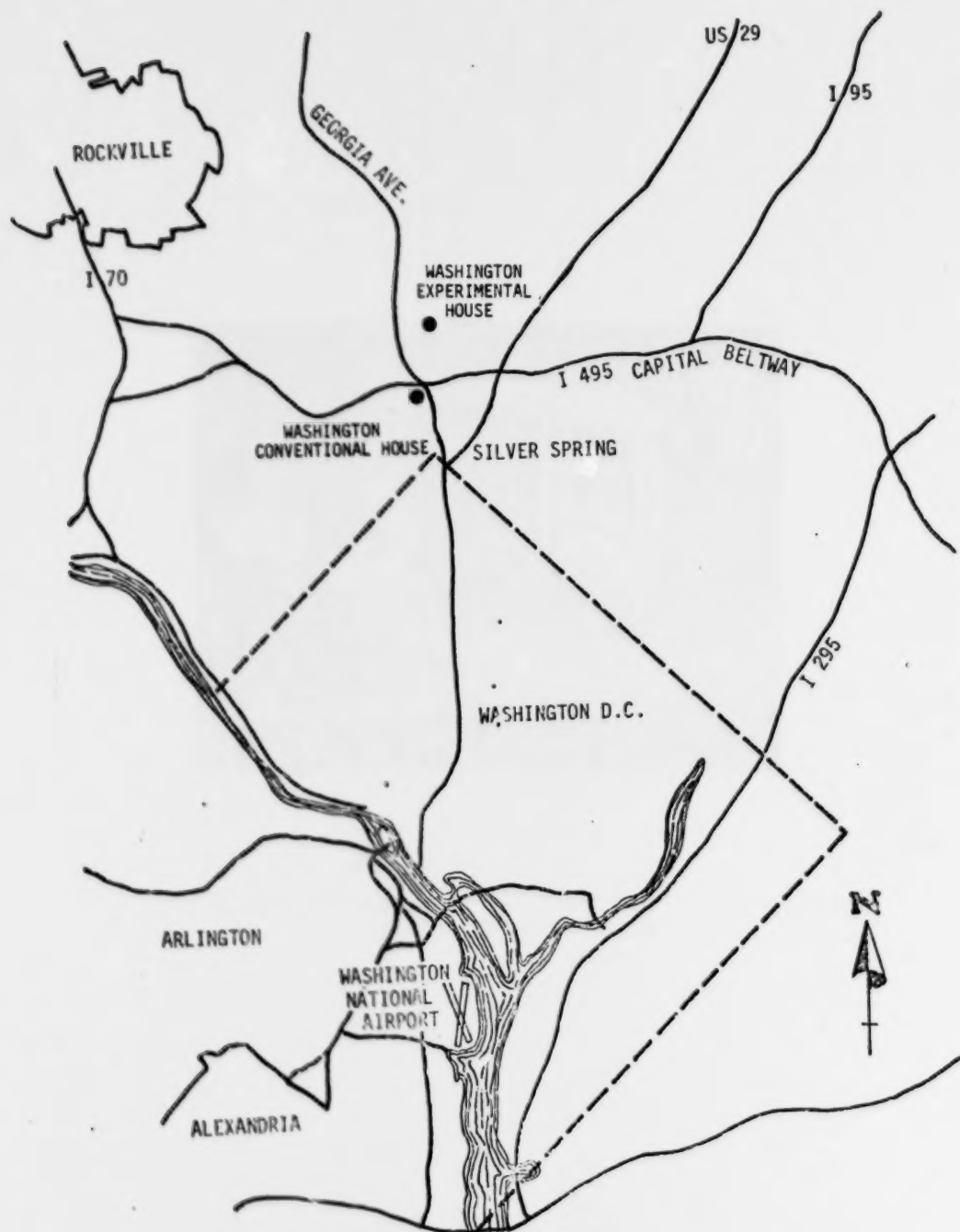
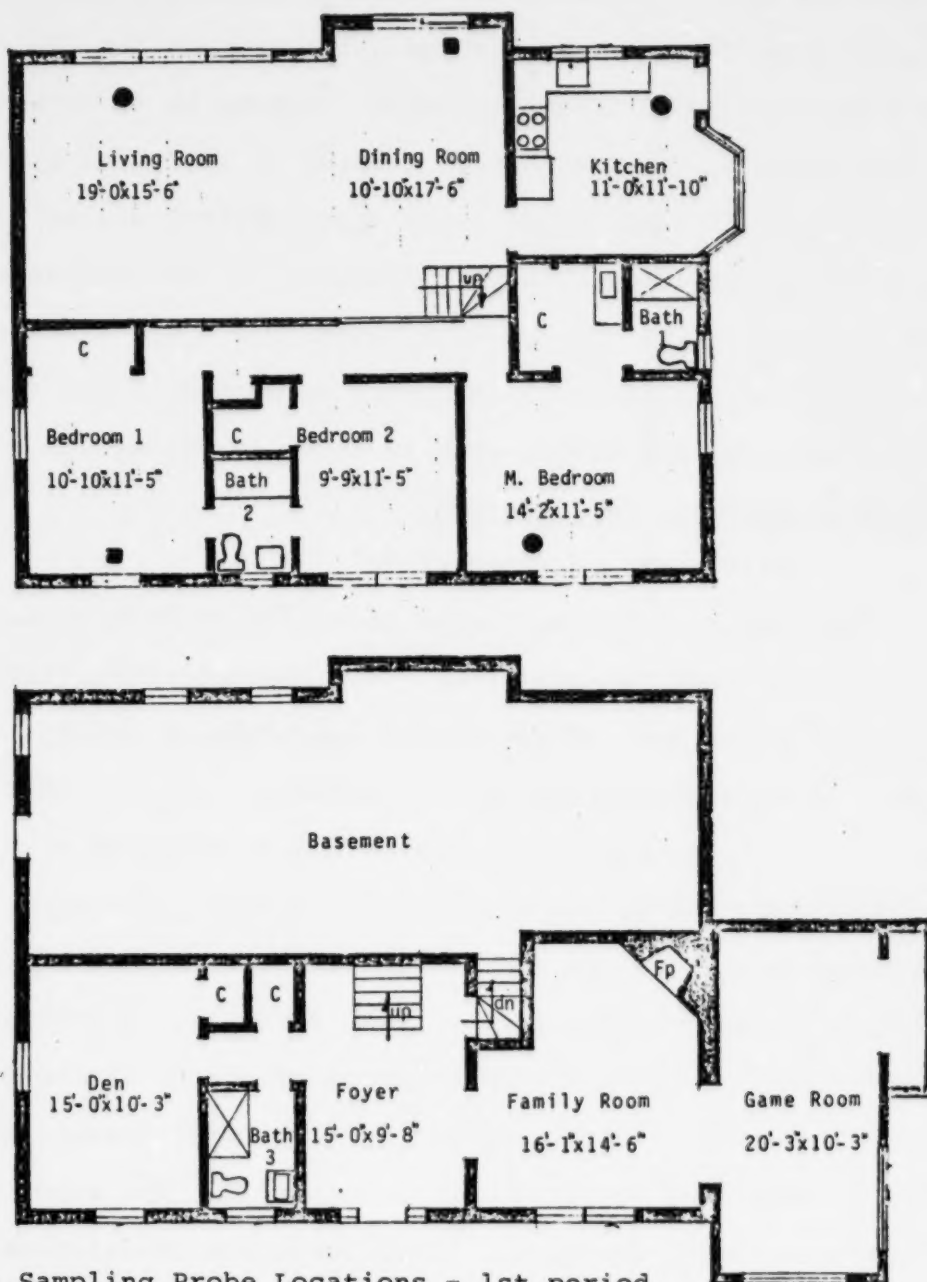


Figure 8. Sketch of the test houses in relationship to the Washington, D.C., area.



- - Sampling Probe Locations - 1st period
- - Sampling Probe Locations - 2nd period

Figure 9. Floor plan of the Washington, D.C., conventional house showing sampling probe locations.

of extreme heat. Under normal summer conditions, heat is removed from the house by a large attic exhaust fan, in conjunction with open screened windows. Figure 10 is a photograph of the experimental residence. Cooking is performed with an electric stove. The residence is approximately 3.2 km (2 mi) north of the Capital Beltway. (A sketch of the residence with respect to the city of Washington, D.C., was presented in Figure 8.) Location of the sampling probes in the kitchen, master bedroom, and living area is shown in Figure 11.

Baltimore Conventional, Attached

° Baltimore, Maryland 21236

The family in the Baltimore Conventional Home consists of two adults and two children. This residence is a two-story attached duplex unit of wood frame and aluminum siding. Figure 12 is a photograph of the residence. The house is heated with a gas forced-air system and is equipped with a conventional central air conditioning system. The house is approximately 3-4 y old and was constructed without storm windows or thermal pane glass. This residence is located in a small subdivision a few miles north of the Baltimore Beltway on U.S. Route 1; a sketch of the location with respect to the City of Baltimore is presented in Figure 13. The floor plan of the residence, Figure 14, illustrates the positioning of the sampling probes.



Figure 10. Photograph of the Washington, D.C.,
experimental house.

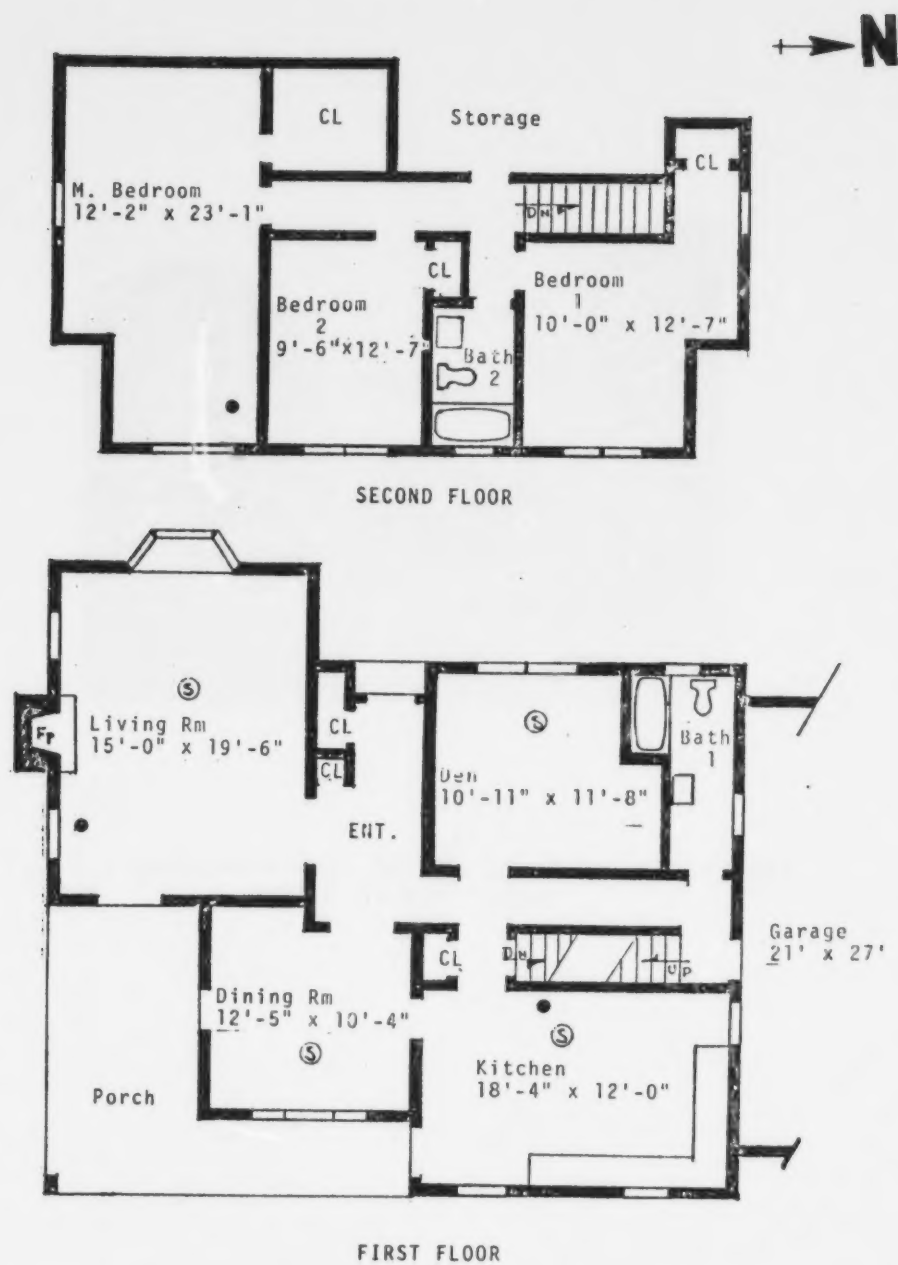


Figure 11. Floor plan of the Washington, D.C., experimental house showing sampling probe locations.



Figure 12. Photograph of the Baltimore conventional house.

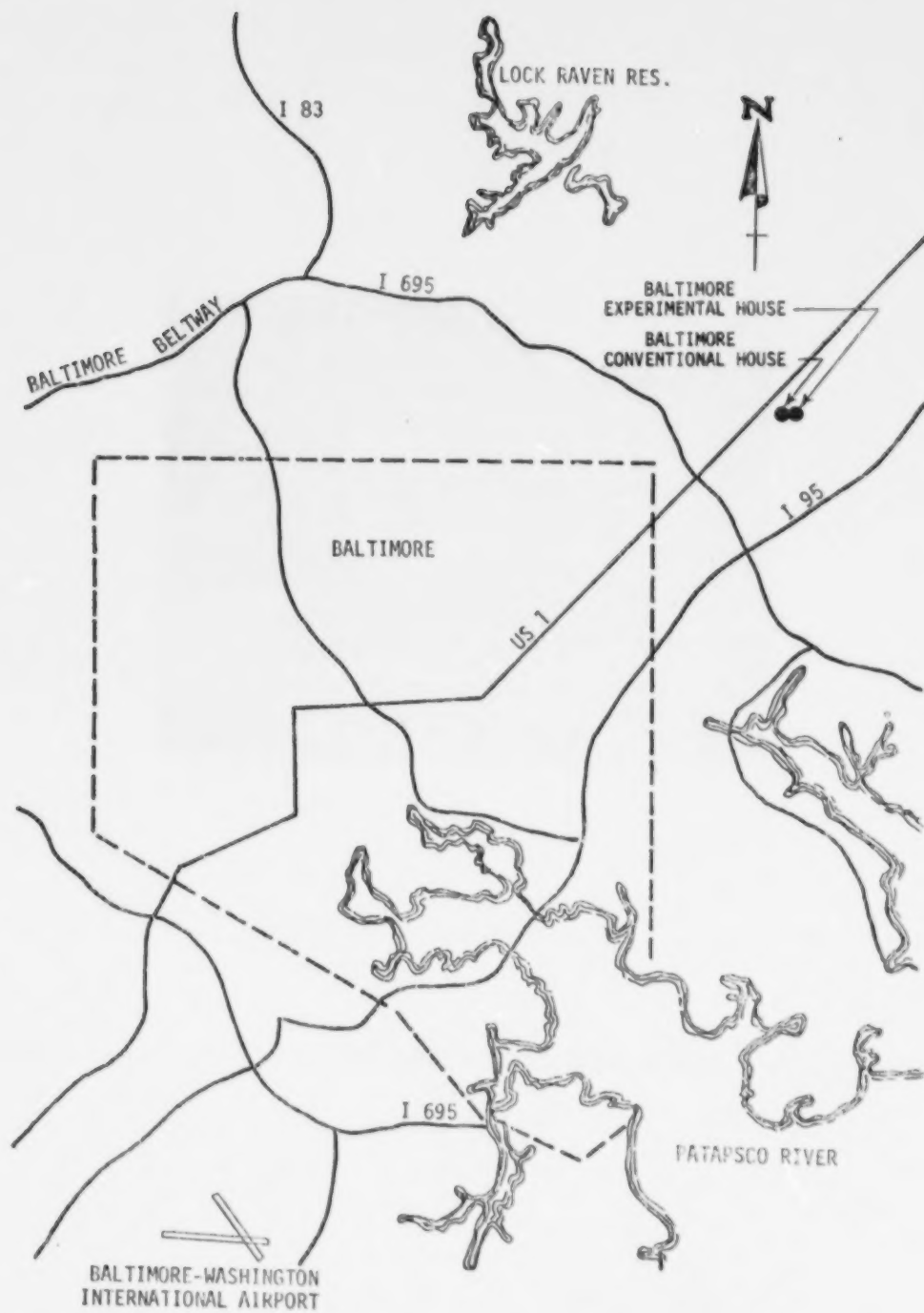
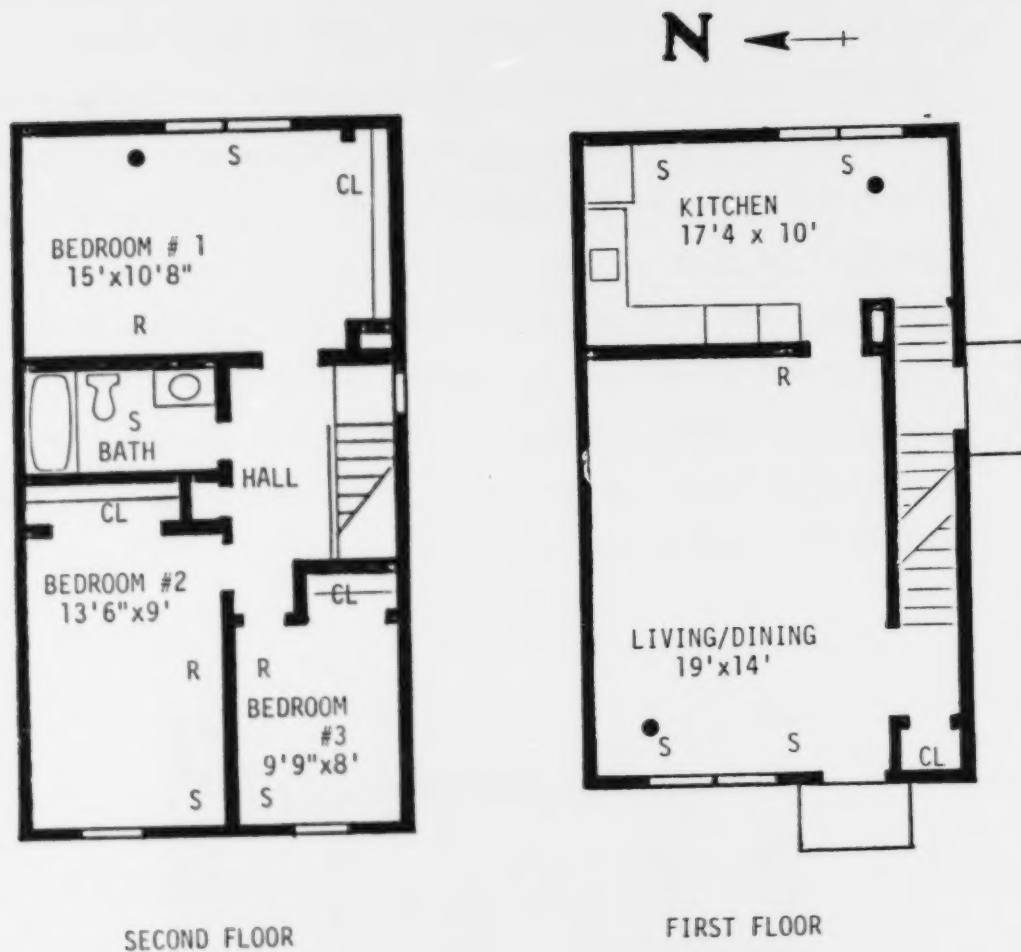


Figure 13. Sketch of the test houses in relationship to the city of Baltimore.



● - Sampling Probe Locations

Figure 14. Floor plan of the Baltimore conventional house showing sampling probe locations.

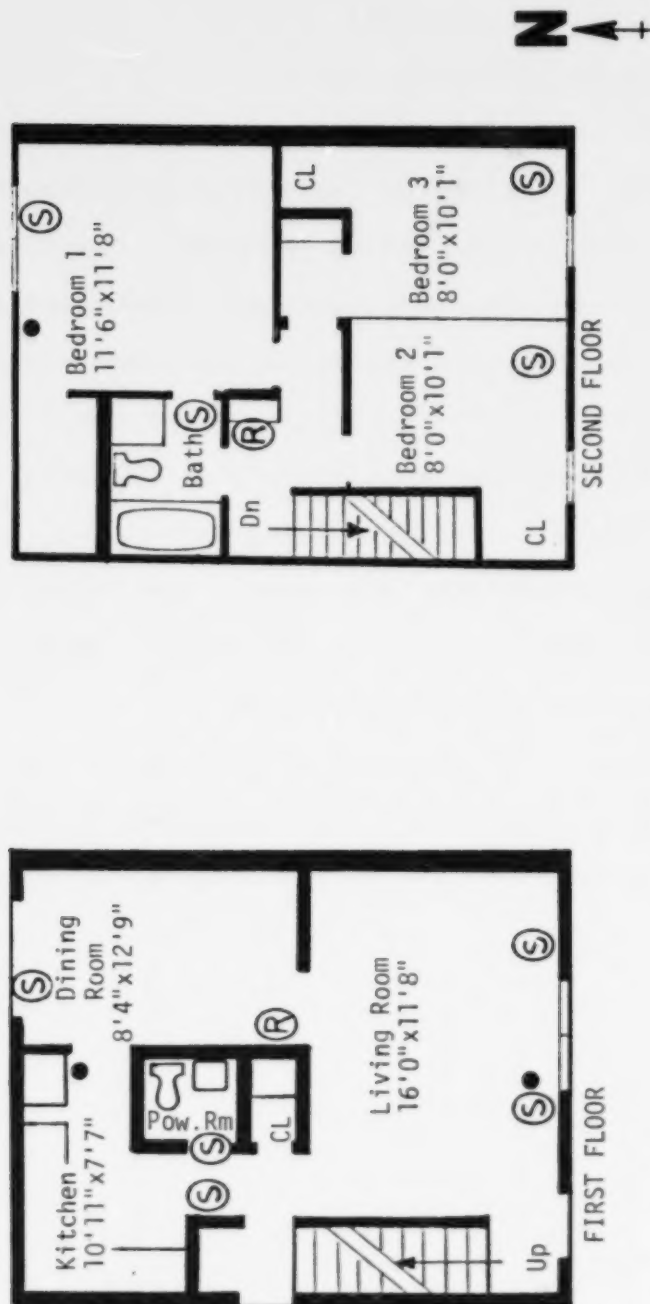
Baltimore Experimental, Attached

° Baltimore, Maryland 21236

A mother and her two children reside in the attached two-story duplex unit of frame/aluminum siding construction. Figure 15 is a photograph of the experimental residence. This unit is heated and cooled by a General Electric heat pump forced-air heating and cooling system. This structure is identical in size to that of the Baltimore conventional residence, but is a newer structure. Its construction incorporates additional insulation and storm windows. The residence is located within a block of the conventional residence as shown in Figure 13. The floor plan in Figure 16 depicts the sampling locations.



Figure 15. Photograph of the Baltimore experimental house.



● - Sampling Probe Locations

Figure 16. Floor plan of the Baltimore experimental house showing sampling probe locations.

Denver Conventional, Detached

° Denver, Colorado 80218

A mother and her 5-y-old daughter are the primary residents of this house. A friend of the family is a frequent visitor to the home in the evening and on weekends. The friend's daughter, also 5-y-old, usually stays overnight throughout the week.

The house, shown in Figure 17, is constructed of wood and brick and is one of the few single-family dwellings within a few blocks of downtown, most streets in the area are heavily traveled, especially during morning and evening rush hours.

Heating is provided by a natural gas forced air furnace. No air conditioning is used in the house. Both cooking and hot water heating are also done with gas.

The location of the house in respect to downtown Denver is presented in Figure 18. The floor plan of the residence, Figure 19, illustrates the positioning of the sampling probe.



Figure 17. Photograph of the Denver conventional house.

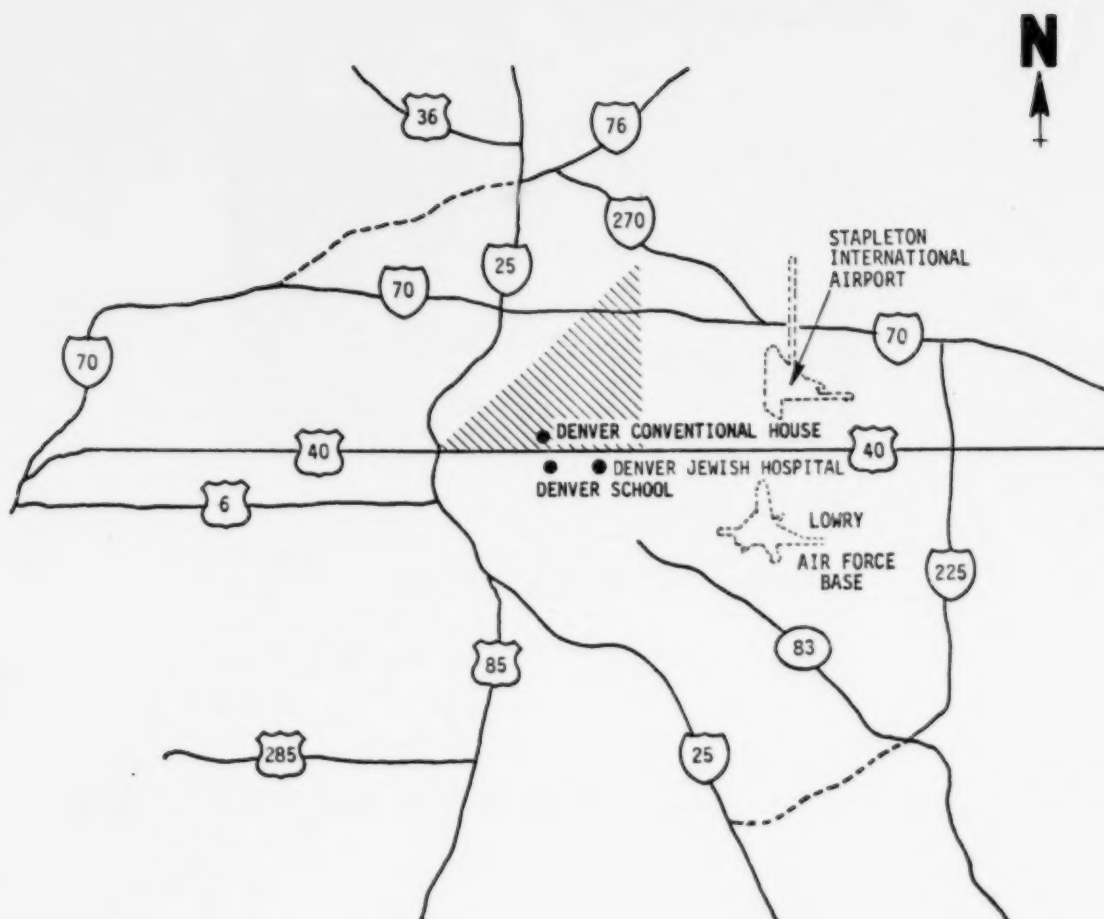
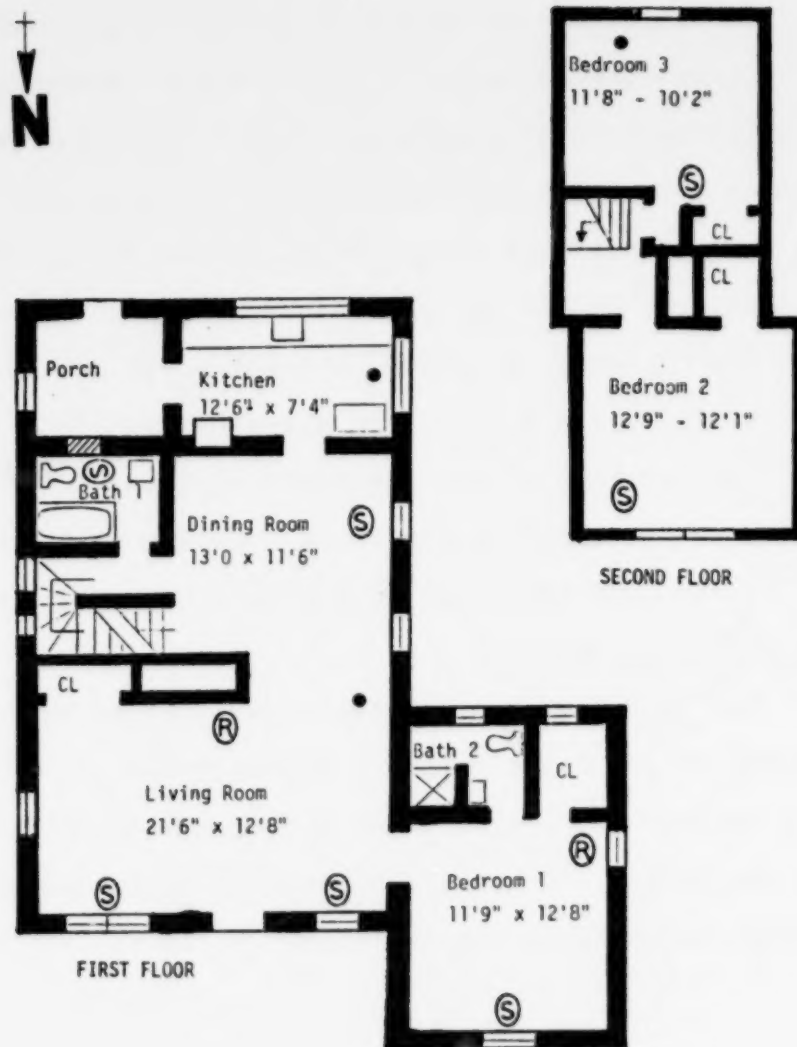


Figure 18. Sketch of the test buildings in relationship to the city of Denver.



● - Sampling Probe Locations

Figure 19. Floor plan of the Denver conventional house showing sampling probe locations.

Denver School

The Denver School is attended by approximately 250 students in grades 1 through 6. The brick, two-story structure is the oldest building in the Denver Public School System. A photograph of the structure is provided in Figure 20. It is located within a few blocks of downtown Denver in a residential neighborhood. The school lies between two streets that serve as major traffic arteries into and out of the central business district; consequently, traffic is heavy, particularly in the morning and evening rush hours.

The building is heated with hot water provided by a natural gas-fired boiler. No air-conditioning system exists.

The location of the structure with respect to downtown Denver is presented in Figure 18. Floor plans depicting the location of the sampling probes may be found in Figure 21.

Denver Jewish Hospital

The Denver Jewish Hospital was added to the sampling program by Dr. David Shearer, former Project Director for EPA, as a special 3-d project. No photographs or floor plans are available. However, the location of the hospital in the Denver metropolitan area is shown in Figure 18.

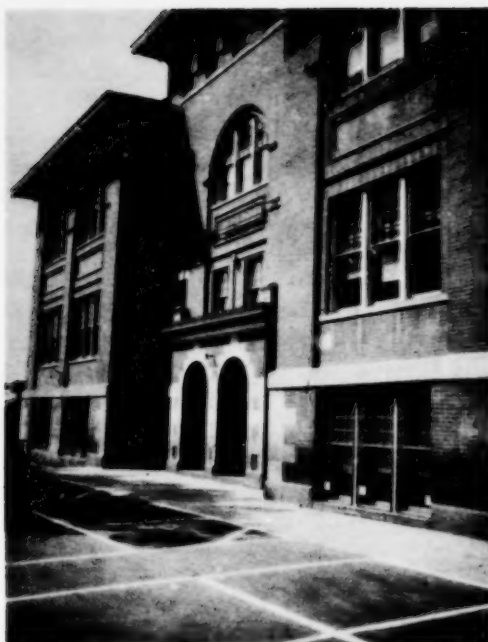


Figure 20. Photograph of Denver School.

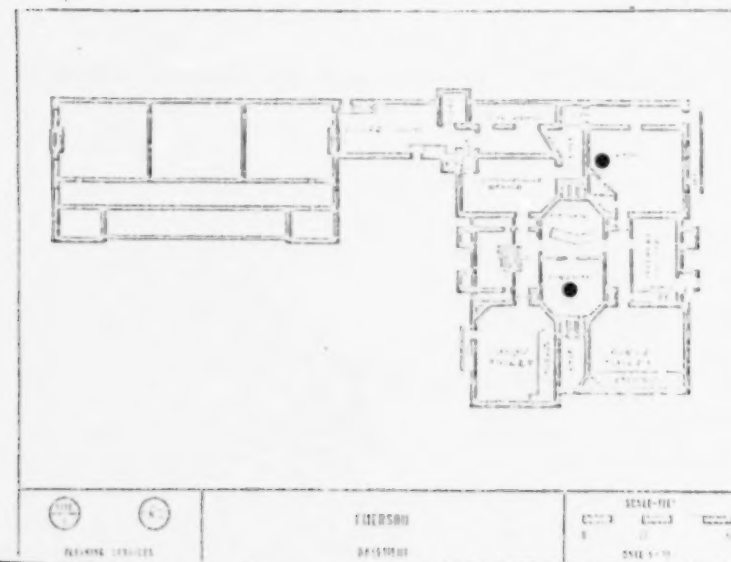
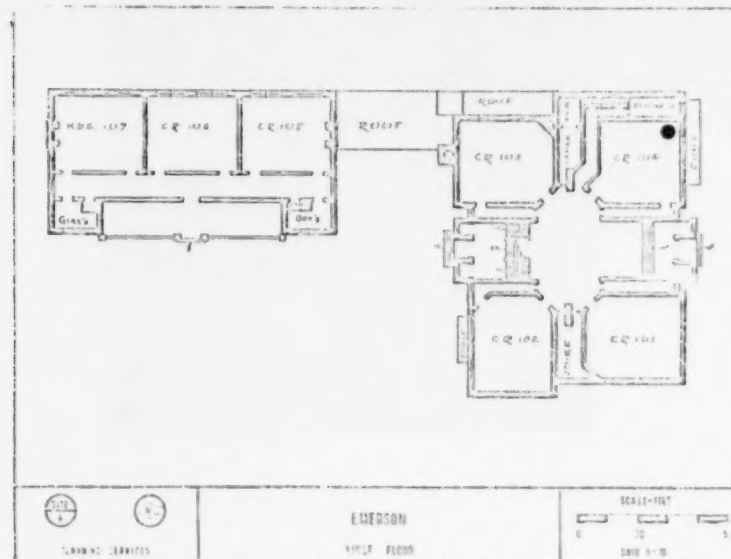
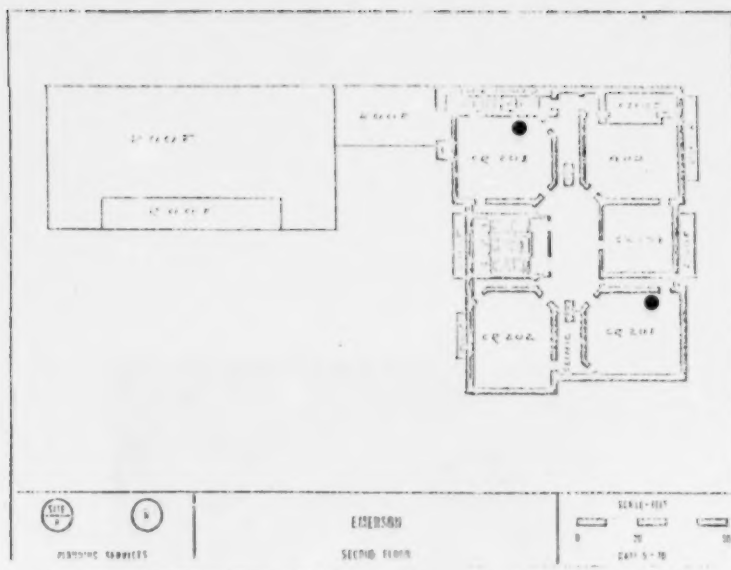


Figure 21. Floor plan of Denver School showing sampling probe locations.

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best available copy.



Chicago Experimental, Detached

° Lansing, Illinois

The residents of this recently constructed split-level house consist of a husband, a wife, and two children. The children are of high school age and are away from home from early morning until late afternoon. The father is also gone most of the day. The house, as shown in Figure 22, is constructed of wood and brick. All of the energy requirements for cooking, heating, etc. are provided by electricity.

The location of the house with respect to the metropolitan Chicago area is provided in Figure 23. The floor plan of the residence, Figure 24, illustrates the position of the sampling probes.

Chicago Conventional, Detached

° Lansing, Illinois

During the first monitoring period, the house was occupied by a husband, wife, and their two children, ages 1 and 4. The wife and the children are usually at home throughout the day. The house, as pictured in Figure 25, is a single-family, two-story, frame structure located on a residential street in Lansing. Heat for the residence is provided by a natural gas forced-air furnace. Energy for cooking and heating water is also natural gas. The house is not air-conditioned. The location of the house with respect to the Chicago area is



Figure 22. Photograph of Chicago experimental house.

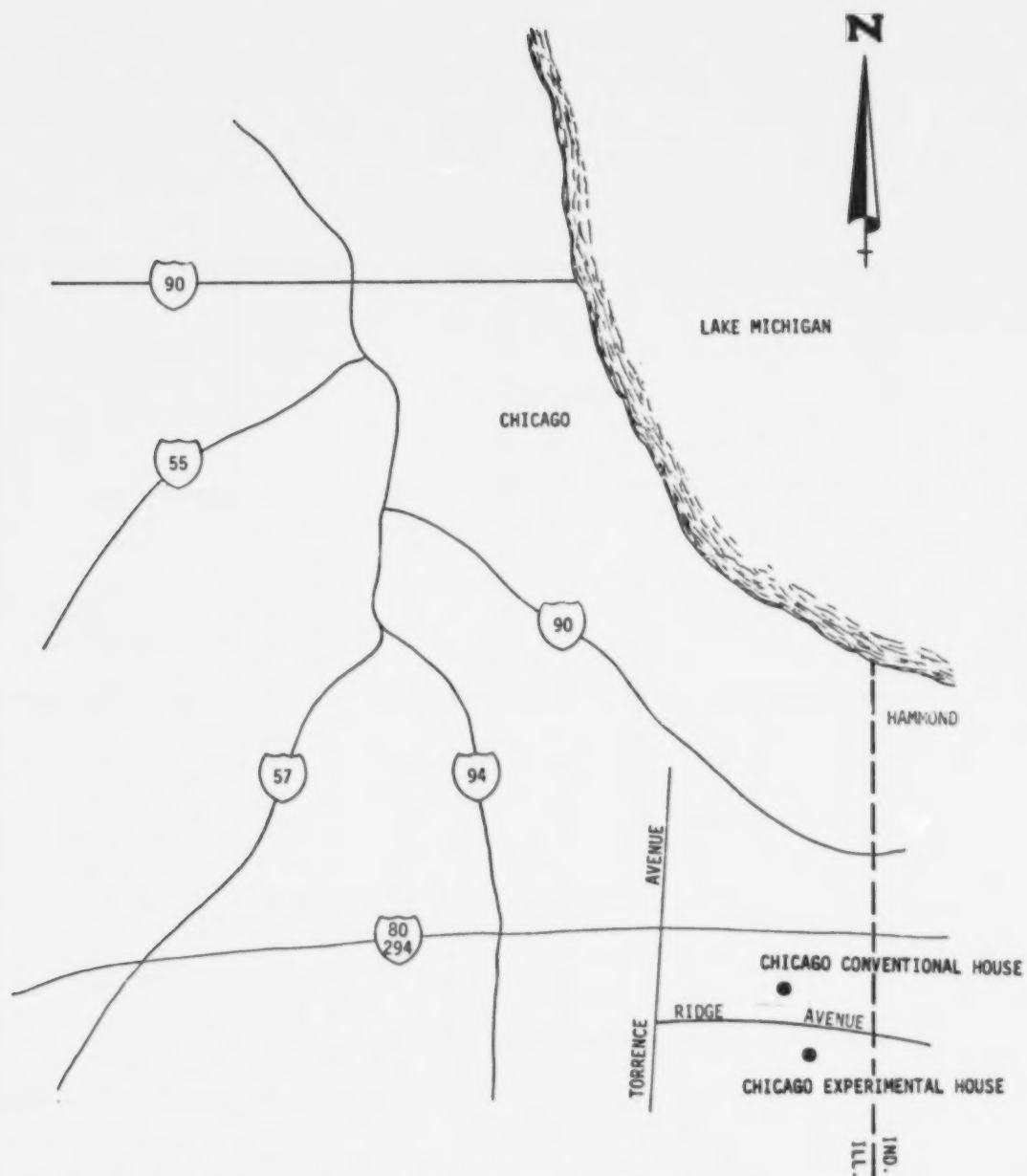


Figure 23. Sketch of test houses in relationship to Greater Chicago.



Figure 24. Floor plan of the Chicago experimental house showing sampling probe locations.



Figure 25. Photograph of Chicago conventional house.

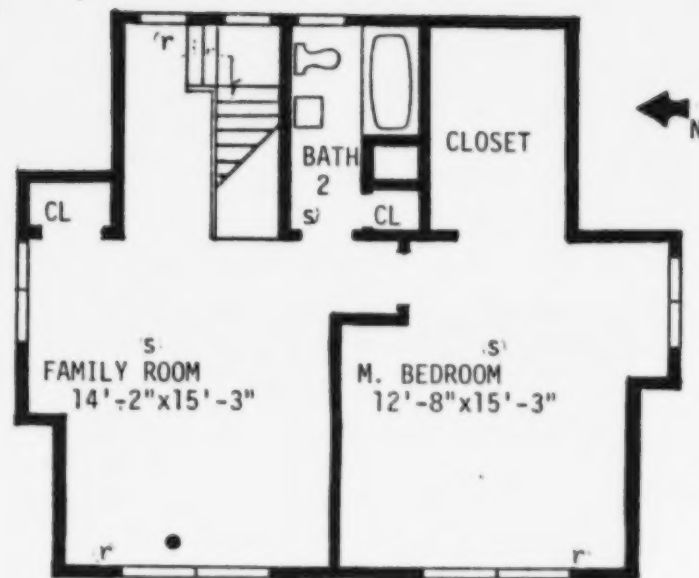
provided in Figure 23. A floor plan of the house showing the location of the sampling probes is presented in Figure 26.

During the second monitoring session, the house was occupied by the field team operating the monitoring instruments. This occurred because the previous family was transferred to another area and the residence was left vacant. The major appliances and heating equipment, as well as sampling probe location, remained the same for the second session.

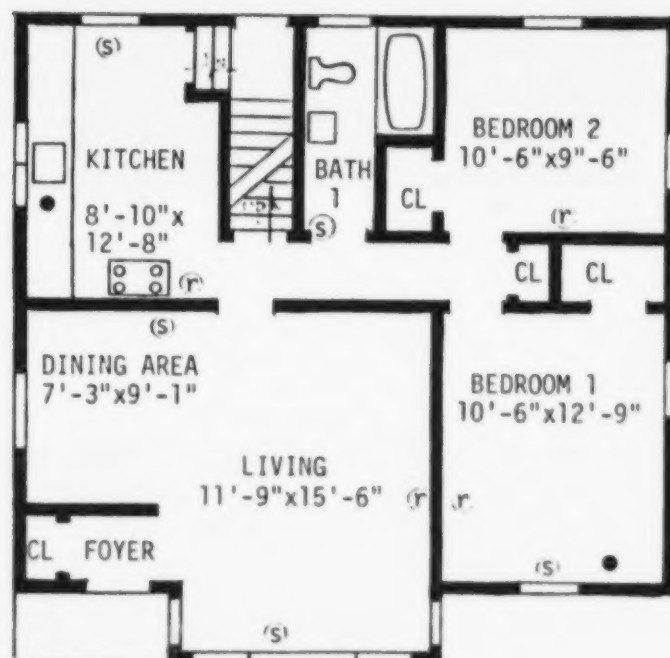
Pittsburgh, Mobile #1

° Baden, Pennsylvania

A photograph of the mobile home is provided in Figure 27. The home is occupied by two retired women, both of whom are approximately 75 y of age. Both of the occupants are in the residence throughout the day. The home is situated in a mobile home sales center on the east bank of the Ohio River directly across from a Jones and Laughlin Steel plant near Baden, Pennsylvania (see Figure 28). A major highway, approximately 27 m (89 ft) from the residence, carries heavy traffic volume throughout the day. Energy from heating is supplied from a kerosene-fired, forced-air furnace. A propane cylinder supplies energy to the stove and water heater. Air-conditioning requirements are met with a conventional, central air-conditioning unit. A floor plan of the mobile home showing sampling probe locations is provided in Figure 29.



SECOND FLOOR



FIRST FLOOR

● Sampling Probe Locations

Figure 26. Floor plan of Chicago conventional house showing sampling probe locations.



Figure 27. Photograph of Pittsburgh mobile home #1.

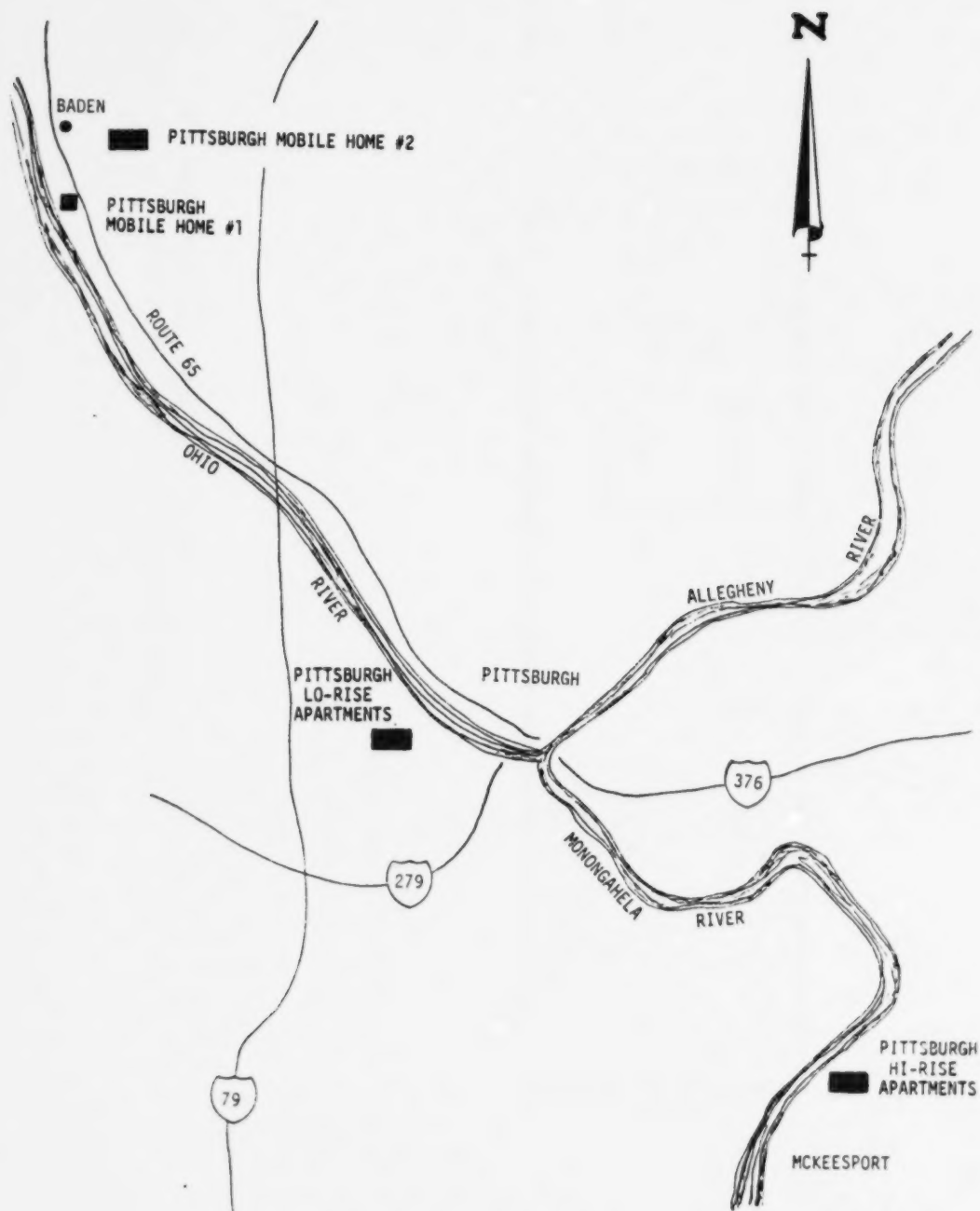
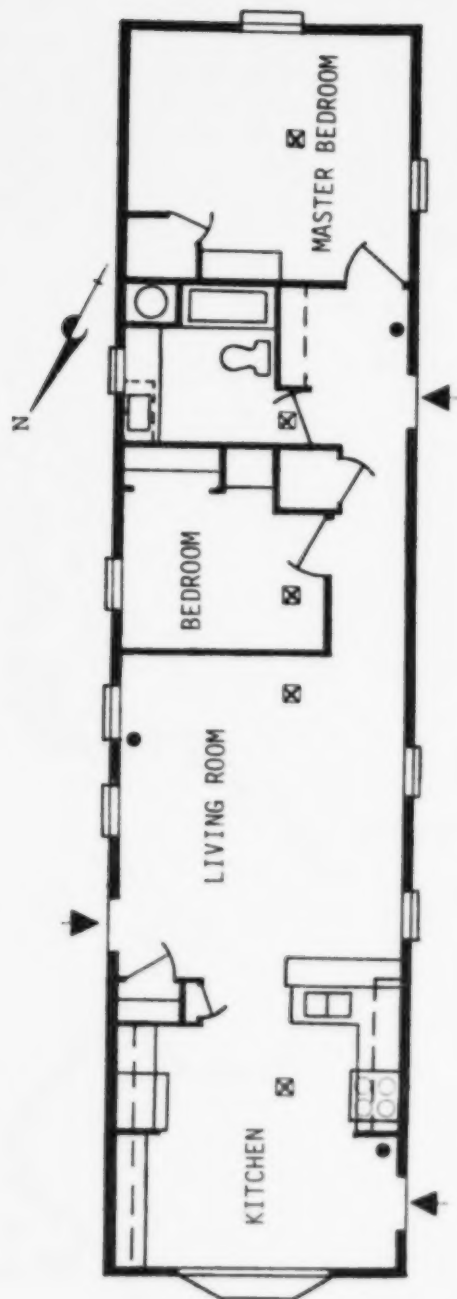


Figure 28. Sketch of test dwellings in relationship to Greater Pittsburgh.



● Sampling Probe Locations

Figure 29. Floor plan of Pittsburgh mobile home #1 showing sampling probe locations.

Pittsburgh, Mobile #2

° Baden, Pennsylvania 15005

The mobile home, as shown in Figure 30, is located on a hill above the Ohio River near Baden, Pennsylvania. Figure 28 locates the site in relation to Pittsburgh. The home is occupied by two adults and one child. A kerosene-fired, forced-air furnace supplies heat. Energy for cooking is supplied by an electric stove. A floor plan, Figure 31, depicts sampling probe locations.

Pittsburgh Lo-Rise

The apartment complex is located on the edge of a hill overlooking the Ohio River approximately 6.5 km (4 mi) from downtown Pittsburgh (see Figure 28). The surrounding structures are apartment complexes and single-family dwellings. Thus, the neighborhood is primarily residential. A photograph of the complex is shown in Figure 32. Each of the 36 apartments has a separate, individually controlled, gas, forced-air furnace.

Pittsburgh Lo-Rise #1 --

° Pittsburgh, Pennsylvania

A mother and her three children are the primary residents. All of the family members are away from home during the day since the mother works and the children are in elementary school (the children range in age from 9 to 5). The apartment is on the



Figure 30. Photograph of Pittsburgh mobile home #2.



Figure 31. Floor plan of Pittsburgh mobile home #2 showing sampling probe locations.



Figure 32. Photograph of Pittsburgh lo-rise apartments.

second level and has two exterior walls facing northeast and northwest. The apartment is equipped with an electric stove and a gas furnace. The apartment is not air-conditioned. A floor plan, Figure 33, depicts sampling locations.

Pittsburgh Lo-Rise #2 --

° Pittsburgh, Pennsylvania

A husband and wife occupy the apartment with their two children, ages 8 and 2. At least part of the family is at home at all times. The apartment is on the third level and has two exterior walls facing northeast and northwest. The apartment is equipped with an electric stove and gas forced-air furnace. The unit is not air-conditioned. A floor plan, Figure 34, depicts sampling locations.

Pittsburgh Lo-Rise #3 --

° Pittsburgh, Pennsylvania

A husband and wife occupy the apartment with their two children. The apartment is on the second level and has one exterior wall facing northeast. The apartment has an electric stove and a gas forced-air furnace. A floor plan, Figure 35, shows sampling probe locations.

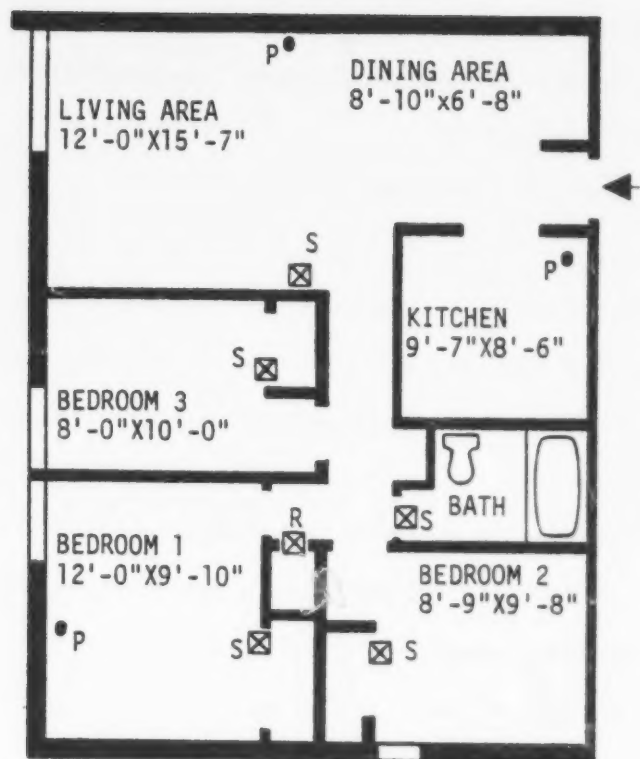
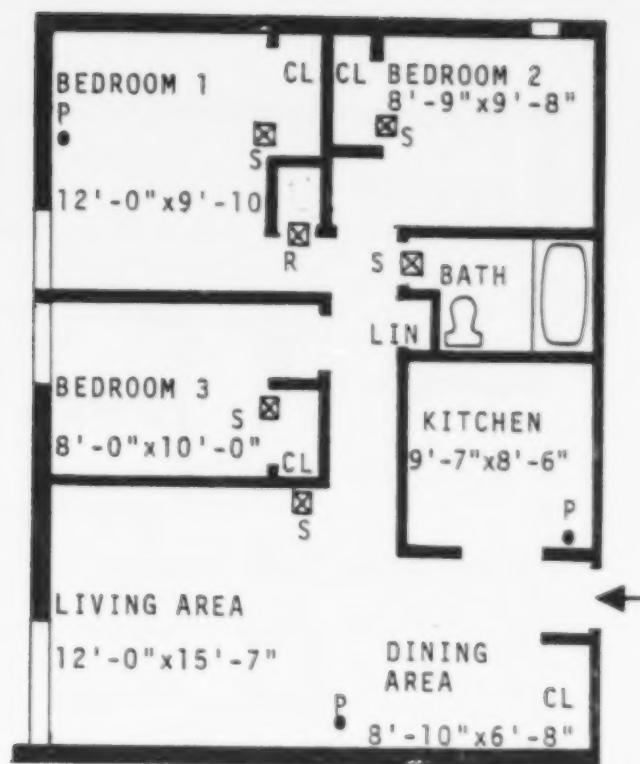


Figure 33. Floor plan of 10-rise #1 showing sampling probe locations.



Figure 34. Floor plan of lo-rise #2 showing location of sampling probes.



● - Sampling Probe Locations

Figure 35. Floor plan of 10-rise #3 showing location of sampling probes.

Pittsburgh Hi-Rise

The apartment complex is located on a hill overlooking the Monongahela River approximately 18 km (11 mi) from downtown Pittsburgh (see Figure 28). The structure, located in downtown McKeesport, is an 11-story building surrounded by other residential and commercial structures. A photograph of the hi-rise complex is shown in Figure 36. Each apartment has an individually controlled gas, forced-air furnace heating system and an electric central cooling system.

Pittsburgh Hi-Rise #1 --

◦ McKeesport, Pennsylvania

A retired husband and wife, the primary residents of this apartment, remain at home throughout the day. The unit has one exterior wall which faces to the west. The apartment is equipped with all electric appliances and electric cooling system. The heating system is a gas forced-air type furnace. A floor plan of the apartment showing sampling probe location is provided in Figure 37.

Pittsburgh Hi-Rise #2 --

◦ McKeesport, Pennsylvania

The apartment is occupied by a retired couple, both of whom are over 60 y of age. Both occupants are in the residence throughout the day. Energy for heating is supplied by



Figure 36. Photograph of Pittsburgh hi-rise apartments.

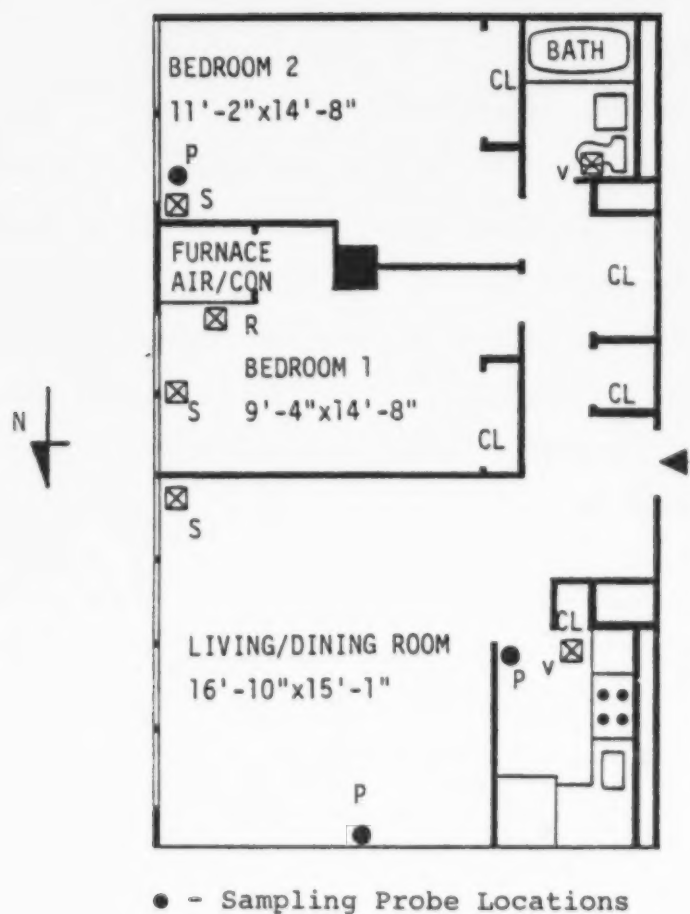


Figure 37. Floor plan of Pittsburgh hi-rise apartment #1.

a gas-fired, forced-air furnace. Air conditioning is supplied by an electric central air conditioning unit. All kitchen appliances are electric. A floor plan, Figure 38, depicts sampling probe locations.

Pittsburgh Hi-Rise #3 --

° McKeesport, Pennsylvania

A retired couple, both of whom are over 60 y of age, are the primary residents of this apartment. Both occupants remain in the residence most of the day. The unit is equipped with electric appliances and an electric central air-conditioning system. The heating system is a gas-fired, forced-air furnace. A floor plan of the unit showing sampling probe location is provided in Figure 39.

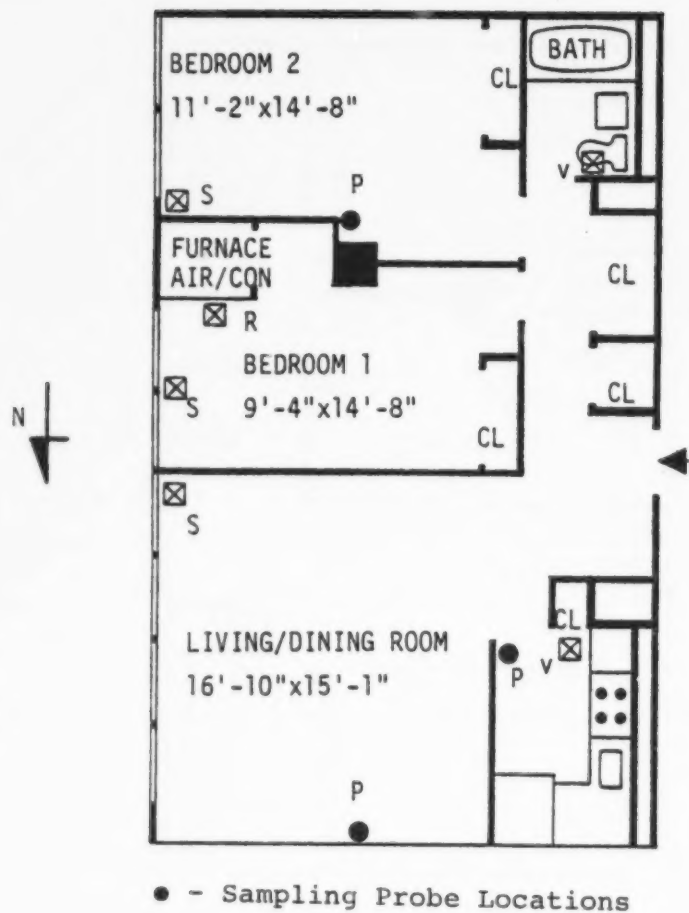


Figure 38. Floor plan of Pittsburgh hi-rise apartment #2.

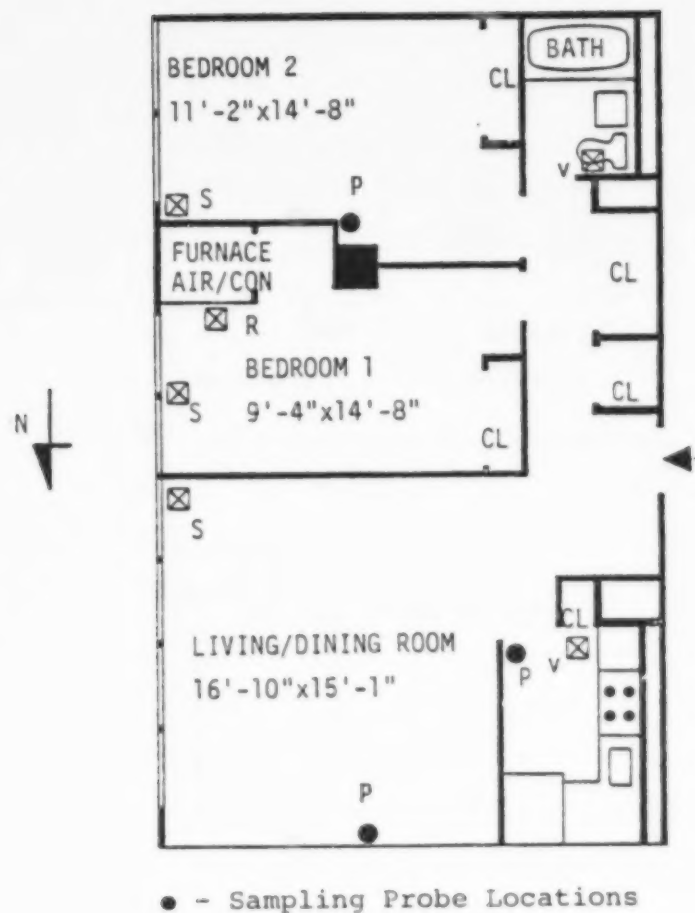


Figure 39. Floor plan of Pittsburgh hi-rise apartment #3.

Section 3

MONITORING TECHNIQUES

The indoor/outdoor monitoring program incorporated continuous, intermittent, and grab-sampling techniques for measurement of airborne pollutants, together with sensors for the recording of wind speed and direction, temperature, and relative humidity. In addition to these measurements, energy consumption parameters, such as the total dwelling energy usage and the energy specifically required for heating and air-conditioning, were measured on a continuous basis.

The sampling system is schematically presented in Figure 40. Air samples from each of four locations (three indoor, one outdoor ambient) were carried through 9.5 mm (3/8 in.) o.d. Teflon tubing at a rate of 10 l/min. At the trailer each sample line was connected to a Teflon pump and three-way Teflon solenoid valve. When the Teflon solenoid valve was activated, the sample was introduced into a 91.4 cm by 12.7 mm i.d. (3 ft by 0.5 in.) glass manifold. When the valve was in its nonactivated position, the Teflon pump purged the sampling line. Each valve was activated by a programmer-timer system in a predetermined sequence. This system allowed the air in the manifold to be changed in less than 1 s, and provided for continuous flushing of the sampling lines.

The instruments sampled from the manifold for 60 s prior to the recording of 4 continuous min of data. After the 4 min of data were recorded, the valve on the next sampling

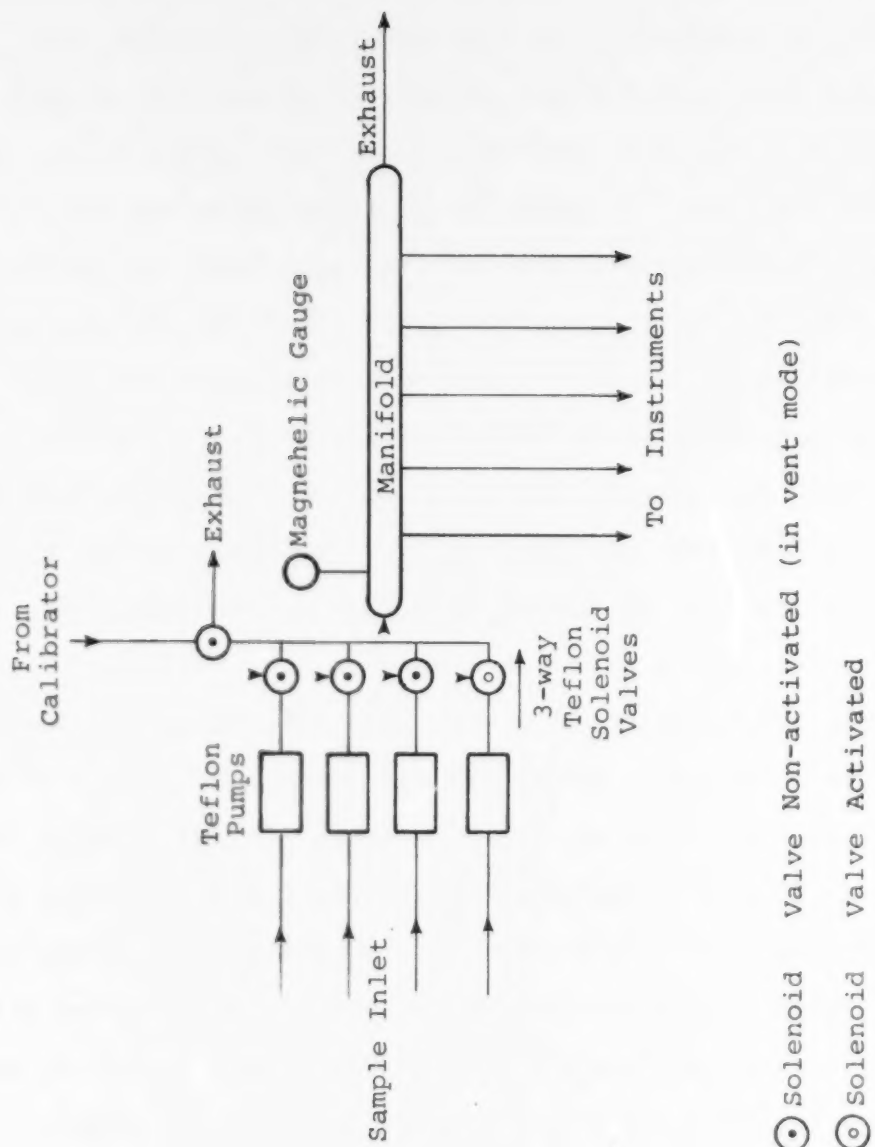


Figure 40. Sampling system for continuous monitors.

line in the sequence was activated by the programmer-timer. The first sample line then returned to its normal purge condition. The process was repeated for each sampling location, four in all, producing a sampling cycle time of 20 min. Thus, three 4-min segments of continuous data were obtained each hour for all continuously monitored pollutants at each of the four sampling locations.

CONTINUOUS MONITORING

Continuous monitoring equipment employed for monitoring indoor-outdoor pollutants is presented in Table 1. A more detailed discussion of the individual instruments and the theory of operations is presented in the following subsections. Detailed instrument descriptions and operating procedures are presented in the operator's manuals.

Nitric Oxide - Total Oxides of Nitrogen (NO-NO_x)

The Meloy CHEMILUMENIZER NA 520 performs continuous dry analysis of nitric oxide (NO), nitrogen dioxide (NO₂) and total oxides of nitrogen (NO_x, NO and NO₂) in gas mixtures. It utilizes the highly sensitive chemiluminescent reaction between NO and ozone (O₃). A high degree of specificity in detecting NO is achieved with the basic reaction and the optical filtering techniques utilized in transmitting the chemiluminescent radiation to a light detector.

The design of the NA 520 was focused on obtaining stable and reliable performance and ease of service and maintenance. Precise pneumatic and thermal control of critical parameters,

TABLE 1. CONTINUOUS MONITORING EQUIPMENT SPECIFICATIONS
EMPLOYED FOR MONITORING INDOOR-OUTDOOR POLLUTANTS

Pollutant	Principle of detection	Manufacturer model	Concentration (ppm)		Response time to 90% or greater	Precision
			Range (s)	Limit of detection		
NO	Chemiluminescent	Meloy-NA-520-2	0-0.5 0-1.0 0-2.0 0-5.0	0.005	100 sec.	+ 1% Full scale
NO _x	Chemiluminescent	Meloy-NA-520-2	0-0.5 0-1.0 0-2.0 0-5.0	0.005	100 sec.	+ 1% Full scale
CO ₂	Nondispersive infrared	Beckman-865	0-2,500 0-50,000	25 500	2.5 sec.	+ 1% Full scale
CO	Nondispersive infrared with flowing ref. cell	Beckman-865	0-50	0.50	2.5 sec.	+ 1% Full scale
O ₃	Chemiluminescent	Meloy-OA-350-2	0-0.5	0.005	15 sec.	+ 2% Full scale
SO ₂	Flame photometric	Meloy-SA-185-2A	0-0.5	0.005	60 sec.	+ 1% Full scale
CH ₄	Flame ionization with selective TCH oxidizer	MSA-11-2	0-5 0-20	0.05 0.20	15 sec.	+ 1% Full scale
THC	Flame ionization with selective THC oxidizer	MSA-11-2	0-5 0-20	0.05 0.20	15 sec.	+ 1% Full scale
Wind/speed direction	Directional synchro speed-d.c. magnet	Bendix Arovane 141/120	0-100 mph 0-540°	0.5 mph 5°	--	+ 1% Full Scale
Temperature/relative humidity	Bimetallic strip/human hair	Weather measure H-311	Adjustable 0-100%	1 °F 1% RH	--	+ 1% Full Scale

and the utilization of proven solid-state circuitry contribute to the performance characteristics of the instrument.

The NA 520 operates from ambient air entirely. A fixed pneumatic sampling system is utilized with an internal pump; the system does not require flow adjustments by the operator. All flow rates are controlled to within $\pm 0.5\%$ throughout the entire range. Its O_3 requirements are generated from dried ambient air. Most of the solid-state electronic systems are mounted on easily accessible plug-in cards.

When ambient air or a mixed gas is introduced to the NA 520, it is separated into two gas flow channels, each of which produces a direct readout of a constituent NO_x compound (see Figure 41). One gas flow channel for NO is passed to a reactor where it is mixed with O_3 . The NO_2 of the mixture remains light passive in the reactor, but the NO reacts with the O_3 to produce high energy, excited NO_2^* molecules:



Almost instantly these NO_2^* molecules revert to a lower energy state NO_2 and at the same time produce light in the near infrared region (0.6 to 3.0 μm):



This light is measured by a photomultiplier tube and electronic circuit in the instrument, the light produced being directly proportional to the NO concentrations of the sample gas stream.

The specially designed reactor chamber operates at reduced pressure, minimizing flow effects and producing maximum light.

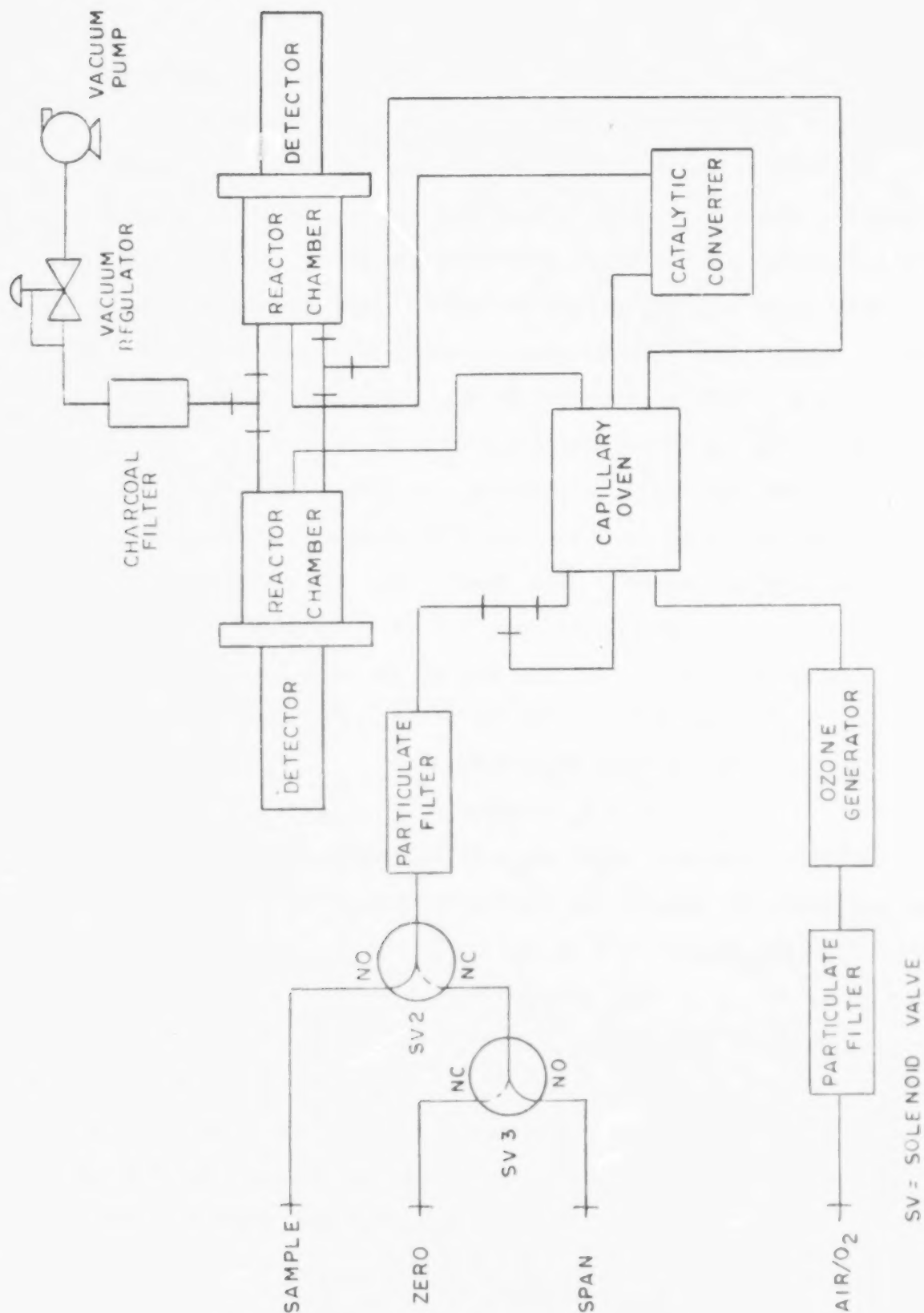


Figure 41. Pneumatic flow diagram of the chemiluminizer.

An electrical discharge ozonator produces high concentration ozone from introduced ambient air for the mixing process.

A cutoff filter is used between the reactor and the photomultiplier tube to avoid interference from other chemiluminescent reactions occurring at lower wavelengths, such as the reaction between O_3 and ethylene, which produces blue light.

The filtered light passes through a chopper assembly ahead of the photomultiplier tube where a rotating blade periodically blocks the light radiation from the reactor chamber. At this blocking instant, the output of the photomultiplier tube equals its "dark current." As the blade moves away, the light increases to an amount proportional to the light intensity in the reactor chamber. This transforms the chemiluminescent signal into a pulsed d.c. light signal to the photomultiplier tube, which is passed through a signal amplifier and demodulator to convert it to a d.c. analog signal; this signal may be conditioned by an output amplifier to provide a 1 V and 100 mV signal that may be read or recorded. Thus, the NO measurement is a continuous measurement through a single channel.

The NO_x measurement is performed in a similar gas path channel where a catalytic converter has been inserted ahead of the reactor chamber. This converter reduces the NO_2 molecules in the ambient air or sample gas mixture to NO in order that it might become active in the mixing process with O_3 . In this fashion not only is the NO of the sample chemiluminescing but the NO_2 which has become NO provides an

additive chemiluminescence; the total is then measured in the same manner as by the NO channel. Thus continuous NO_x readout is provided by the second channel.

The NO₂ concentration is then continuously provided by electronically subtracting the measured NO from the measured NO_x.

The NA 520 provides continuous readout of NO, NO_x, and NO₂ without any switching.

SPECIFICATIONS

Performance Specifications

Ranges:	0 to 0.5 ppm 0 to 1.0 ppm 0 to 2.0 ppm 0 to 5.0 ppm
Minimum Detectable Sensitivity:	0.005 ppm
Noise:	±0.005 ppm
Lag Time:	1 s
Rise Time to 90%:	100 s (all channels)
Fall Time to 90%:	100 s (all channels)
Precision:	±1%
Accuracy:	±1%
Zero Drift:	+0.005 ppm per 24 h ±0.010 ppm per 7 d
Span Drift:	+0.010 ppm per 24 h ±0.015 ppm per 7 d

SPECIFICATIONS (Continued)

Linearity: +1%

Operational Specifications

Unattended Operation: 7 d
(No adjustment of
flow or electrical
systems)

Sample Flow Rate: 800 to 1000 ml/min

Power Requirements: 115 ± V a.c., 50/60 Hz, 300
watts

Outputs: a) Meter in ppm units, selector
switch to read NO, NO₂ or NO_x
channel.
b) Recorder outputs (for each
channel): 0-1 V, 0-100 V

Relative Humidity Range: 10 to 95%

Ambient Temperature Range: 10° to 40° C for specified
specifications

Configurational Specifications

Weight: 27.2 kg (60 lbs)

Case Dimensions: 48 cm (19 in)W x 50.8 cm (20 in)L
x 31 cm (12.25 in)H

Mountings Available: a) Bench
b) Rack (optional)

Sample Pump: Internal

Carbon Dioxide (CO₂)

The Beckman Model 865 Infrared Analyzer automatically and continuously determines the concentration of CO₂ in a flowing mixture. The analysis is based on a differential measurement of the absorption of infrared energy. The instrument has a wide range of applications, subject only to the limitation that the analysis must involve determination of a single component,

which must absorb infrared energy. Within the analyzer, two equal-energy infrared beams are directed through two optical cells: a flowthrough sample cell and a sealed reference cell. Solid-state electronic circuitry continuously measures the difference between the amounts of infrared energy absorbed in the two cells. This difference is a measure of the concentration of the component of interest in the sample. Read-out is on a front-panel meter with 0-to-100 scale. In addition, a field-selected output for a potentiometric (voltage) recorder is provided. The analyzer utilizes an optional plug-in linearizer circuit board to give linear read-out of concentration values on the meter and on a potentiometric recorder.

The electronic circuitry utilizes plug-in printed circuit boards with solid-state components. This feature provides the ultimate in reliability, facilitates servicing, and permits the inclusion of various options, such as current output, by addition of the appropriate circuit boards.

As shown in Figure 42, the Model 865 produces infrared radiation from two separate energy sources. Once produced, this radiation is beamed separately through a chopper which interrupts it at 10 Hz. Depending on the application, the radiation may then pass through optical filters to reduce background interference from other infrared-absorbing components.

The infrared beams pass through two cells; one a reference cell containing a nonabsorbing background gas, the other a sample cell containing a continuous flowing sample.

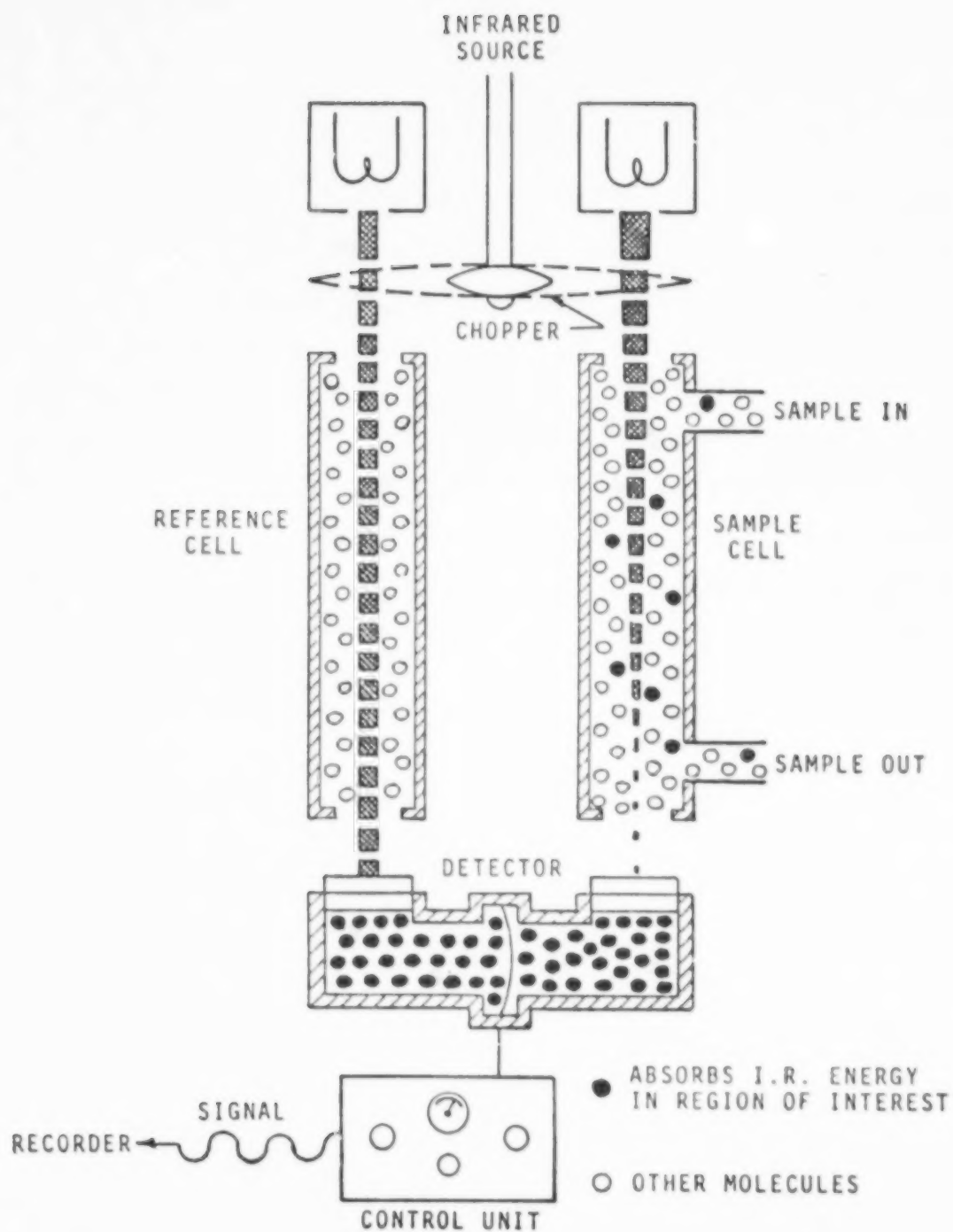


Figure 42. Schematic diagram of a typical nondispersive infrared CO_2 monitor.

SPECIFICATIONS

Range:	0-50 ppm 0-2500 ppm 0-50,000 ppm
Accuracy:	1% of full scale
Span Drift:	$\pm 1\%$ of fullscale in 24 h
Zero Drift:	$\pm 1\%$ of fullscale in 24 h
Ambient Temperature Range:	30 ° to 120 °F (-1 ° to 49 °C)
Line Voltage:	115 ± 15 V rms.
Line Frequency:	50/60 ± 0.5 Hz.
Power Consumption:	400 w
Electronic Response Time (0 to 90% of full scale):	Switch selection of fast or slow response FAST - Switch position provides 5.0-s response (optional 1.0-s response obtainable by clipping jumpers). SLOW - Switch position provides 2.5-s response.
Output:	Standard (Potentiometric) - 0 to 10, 0 to 100 mV, 0 to 1, 0 to 5 V d.c. (field- selectable). Optional (Current) - 4 to 20 and 10 to 50 mA, d.c. (field-selectable). or, Linearized (Potentiometric) - 0 to 10, 0 to 5 V, d.c. (field-selectable).

During operation, a portion of the infrared radiation is absorbed by the component of interest in the sample, with the percentage of infrared radiation absorbed being proportional to the component concentration. The detector is a "gas microphone" on the Luft principle. It converts the difference in energy between sample and reference cells to a capacitance change. This capacitance change, equivalent to component concentration, is amplified and indicated on a meter, and used to drive a recorder.

Carbon Monoxide (CO)

The Beckman Model 865 Infrared Analyzer automatically and continuously determines the concentration of CO in a flowing mixture. The analysis is based on a differential measurement of the absorption of infrared energy. The instrument has a wide range of applications, subject only to the limitation that the analysis must involve the determination of a single component, which must absorb infrared energy.

Within the analyzer, two equal-energy infrared beams are directed through two optical cells: a flowthrough sample cell and a flowthrough reference cell. Air passing through the reference cell is first passed through a scrubber to remove any CO present. Solid-state electronic circuitry continuously measures the difference between the amounts of infrared energy absorbed in the two cells. This difference is a measure of the concentration of the component of interest in the sample. Readout is on a front-panel meter with 0-to-100 scale. In addition, a field selectable output for a

potentiometric (voltage) recorder is provided as standard. A field-selectable output for a current-type recorder or controller is obtainable through use of an optional plug-in circuit board. The analyzer utilizes an optional plug-in linearizer circuit board to give linear readout of concentration values on the meter and on a potentiometric recorder.

The electronic circuitry utilizes plug-in printed circuit boards with solid-state components. This feature provides the ultimate in reliability, facilitates servicing, and permits the inclusion of various options, such as current output, by addition of the appropriate circuit boards.

As shown in Figure 43, the Model 865 produces infrared radiation from two separate energy sources. Once produced, this radiation is beamed separately through a chopper which interrupts it at 10 Hz. Depending on the application, the radiation may then pass through optical filters to reduce background interference from other infrared-absorbing components.

The infrared beams pass through two cells; one a flow-through reference cell containing CO-free air, the other a sample cell containing a continuous flowing sample.

During operation, a portion of the infrared radiation is absorbed by the component of interest in the sample, with the percentage of infrared radiation absorbed being proportional to the component concentration. The detector is a "gas microphone" on the Luft principle. It converts the difference in energy between sample and reference cells to a capacity

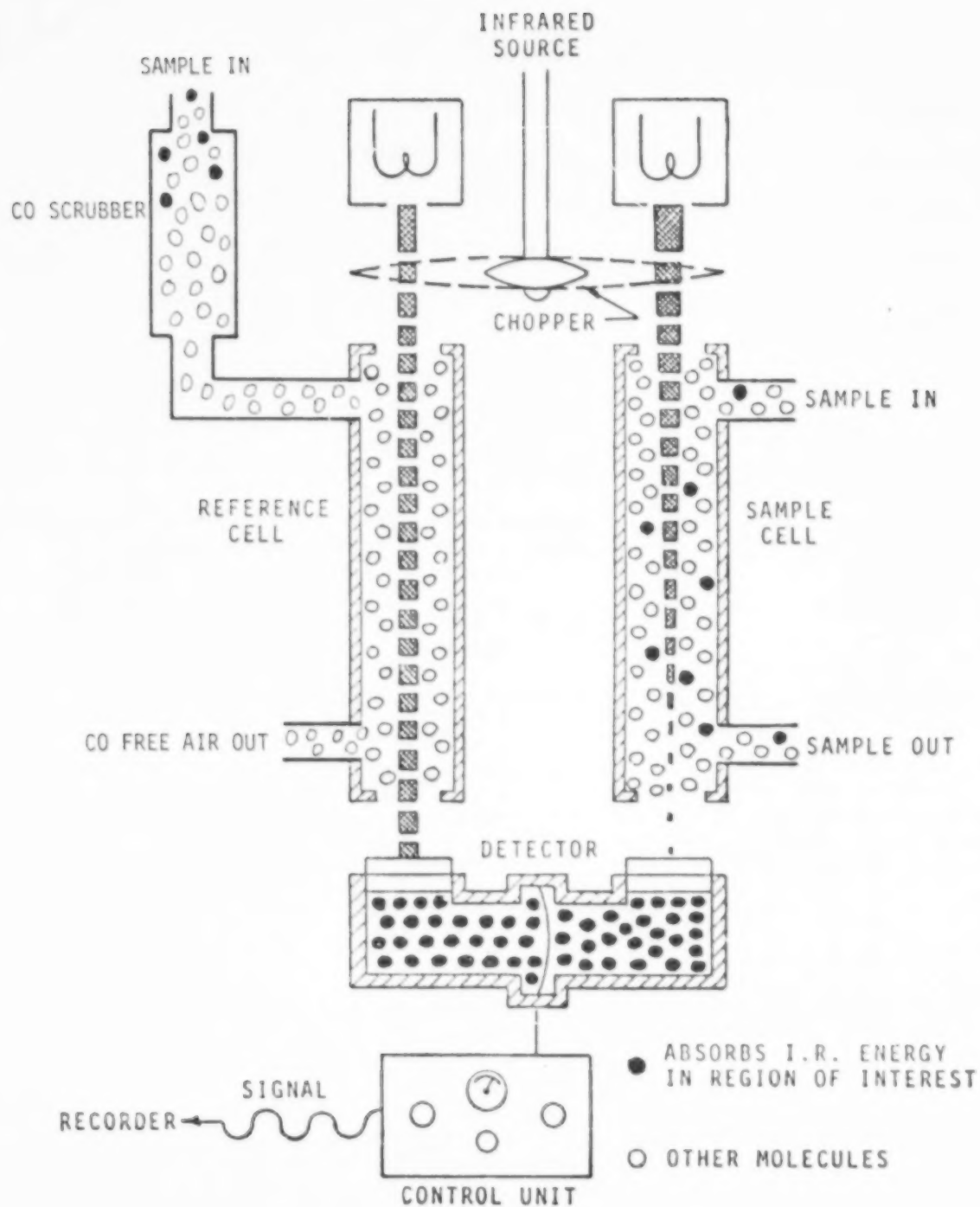


Figure 43. Schematic diagram of a typical nondispersive infrared CO monitor with flowthrough reference cell.

SPECIFICATIONS

Range:	0-50 ppm
Accuracy:	1% of full scale
Span Drift:	<u>+1%</u> of full scale in 24 h
Zero Drift:	<u>+1%</u> of full scale in 24 h
Ambient Temperature Range:	30 ° to 120 °F (-1 ° to 49 °C)
Line Voltage:	115 <u>+15</u> V rms.
Line Frequency:	50/60 <u>+0.5</u> Hz.
Power Consumption:	400 W
Electronic Response (0 to 90% full scale)	Switch selection of fast or slow response FAST - Switch position provides 0.5-s response (optional 1-s response obtainable by clipping jumpers). SLOW - Switch position provides 2.5-s response
Output:	Standard (Potentiometric) 0 to 10, 0 to 100 mV, 0 to 1, 0 to 5 V d.c. (field-selectable). Optional (Current) 4 to 20 and 10 to 50 mA, d.c. (field-selectable) or Linearized (Potentiometric) 0 to 10, 0 to 100 mV, 0 to 1, 0 to 5 V, d.c. (field-selectable).

change, equivalent to component concentration, is amplified and indicated on a meter, and used to drive a recorder.

Ozone (O_3)

The Meloy Model OA 350-2 Ozone Analyzer provides continuous and precise measurement of the concentration of ozone in gas streams. Its operation is based on the chemiluminescent reaction between ozone and ethylene. Model OA 350-2 is a sensitive and economical analyzer with a minimum detectable limit of 1 ppb of O_3 in air. It is intended for continuous service under rugged field conditions. The OA 350-2 is equipped with a built-in calibrator, which allows the user to perform a zero and span calibration on site without need of an external calibration system.

Design of the OA 350-2 was focused on obtaining stable and reliable performance and ease of service and maintenance. Thermal control of the critical elements of the pneumatic and detector systems and temperature-compensated electronic circuits provide stable operation through an ambient temperature range of 10 ° to 40 °C. The use of plug-in boards with proven solid-state circuits provides dependable performance which can easily be maintained.

Operation of the analyzer is based on the gas phase chemiluminescent reaction between O_3 and ethylene molecules, which produces light energy in the 300 to 600 nm range (see Figure 41). In the presence of excess ethylene,

the intensity of light produced is proportional to the concentration of O_3 . This reaction has been found to be free of interferences from other gas present in ambient air.

The O_3 concentration is measured by introducing sample air into the reactor chamber where a special nozzle arrangement mixes the air with an ethylene stream. The light emitted is detected by a photomultiplier tube which converts this energy into an electrical current. This in turn is converted to a voltage, amplified, and displayed on the panel meter.

SPECIFICATIONS

Performance Specifications

Range:	0 to 0.01 ppm 0 to 0.1 ppm 0 to 0.5 ppm 0 to 1.0 ppm 0 to 5.0 ppm 0 to 10.0 ppm
Minimum Detectable Sensitivity:	0.0005 ppm
Noise:	$\pm 0.3\%$ on 0.5 ppm scale
Lag Time:	less than 10 s
Rise Time (95%)	less than 15 s
Fall Time (95%)	less than 15 s
Precision:	$\pm 2\%$ F.S.
Zero Drift:	$\pm 1\%$ F.S. per day on 0.5 ppm scale $\pm 2\%$ F.S. per day on 0.01 ppm scale $\pm 2\%$ F.S. per 3 days on 0.5 ppm scale

Span Drift: less than +1% per day on 0.5 ppm scale
less than +2% per 3 days on 0.5
ppm scale

Linearity: +1% F.S.

Operational Specifications

Unattended Operation: 7 d

(No adjustment of flow
or electrical systems)

Sample Flow Rate: Approximately 500 ml/min

Ethylene Flow Rate: Approximately 30 ml/min

Power Requirement: 115 V a.c., 50-60 Hz, 250 W

Outputs: (a) Meter: 0-10 ppm
(b) Recorder: 0-100 mV and 0-1 V

Relative Humidity Range: 10 to 95%

Ambient Temperature Range: 10 -40 °C for specified
specifications

Configuration Specifications

Weight: Approximately 18.1 kg (40 lb)

Case Dimensions: 48 cm (19 in.) w x 50.8 cm
(20 in.) L x 31 cm (12.25 in.)

Mounting Available: (a) Bench (Standard)
(b) Rack (Optional)

Sample Pump: Internal

Sulfur Dioxide (SO₂)

The Meloy Model SA 185-2A PFD Sulfur Dioxide Analyzer performs real time and continuous dry analysis of sulfur dioxide in gas mixtures. It uses the unique Flame Photometric Detection (FPD) technique, U.S. Patent No. 3,489,498, which involves monitoring the intensity of light emitted by sulfur species passing

through a hydrogen-rich flame. The high detection specificity and sensitivity of the analyzer are achieved by a special geometrical arrangement of the burner, and by use of a 394 nm narrow band pass filter and a hydrogen sulfide scrubber.

The SA 185-2A was designed to provide stable and reliable performance and ease of service and maintenance. Precise pneumatic and thermal control of critical elements and the utilization of proven solid-state circuitry contribute to the performance characteristics of the instrument.

Sample air is drawn through the H₂S scrubber and into the detector block by means of a vacuum pump. Hydrogen is supplied to the block under a slight pressure from a cylinder or hydrogen generator (see Figure 44). Both of these gas streams are controlled and regulated to provide a stable diffusion flame while also minimizing the interference from background light produced by the flame. In addition, a 394 nm narrow band pass filter passes the chemiluminescent emission to provide more detection specificity. The emission intensity is measured by a photomultiplier tube (PMT). The PMT is protected from overheating by shields and heat sinks and is regulated by a high voltage power supply which stabilizes the PMT output. The current output of the PMT is converted to a voltage by an electrometer amplifier, which is used as the instrument output.

GAS
CONNECTORS

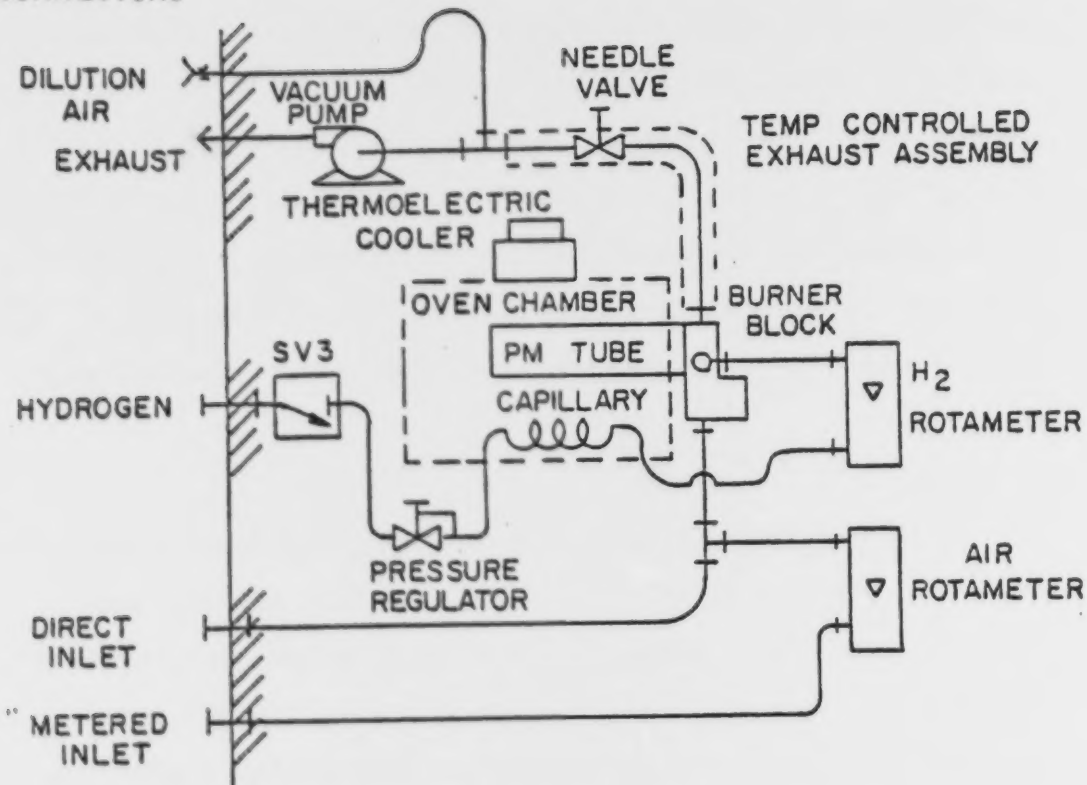


Figure 44. Gas flow diagram.

SPECIAL CO₂ INTERFERENCE TEST FOR MELOY SO₂ ANALYZER

SO₂ concentrations for the GEOMET indoor/outdoor air sampling program were measured using a Meloy Model SA 185 SO₂ analyzer employing a Flame Photometric Detector. Although assured by Meloy Laboratories that variations in CO₂ concentrations do not interfere with SO₂ readings, some question as to the validity of this statement existed since indoor CO₂ readings far exceed ambient concentrations. In order to verify or disprove the question of CO₂ interference, a CO₂ interference test was conducted and its results are presented here.

Procedure

CO₂ interference tests were conducted by first generating SO₂ concentrations by the dilution of 45 ppm SO₂ span gas with zero air. After a stable reading was obtained with the SO₂ analyzer, CO₂ (40,900 ppm) was added to the gas mixture. CO₂ concentrations were monitored with a NDIR CO₂ analyzer. Tests were run at four different SO₂ concentrations. At each SO₂ concentration four levels of CO₂ were added. All values obtained are presented in Table 2.

TABLE 2. RESULTS OF CO₂ INTERFERENCE TEST

	Actual SO ₂ (ppm)	Read SO ₂ (ppm)	CO ₂ (ppm)
Test 1	.050	.050	312
	.050	.040	875
	.050	.030	1525
	.050	.023	2088
Test 2	.095	.095	308
	.095	.075	850
	.095	.055	1500
	.095	.045	2038
Test 3	.23	.25	0
	.23	.23	300
	.23	.18	833
	.23	.14	1450
	.23	.115	1975
Test 4	.330	.373	0
	.330	.330	300
	.330	.265	813
	.330	.205	1450
	.330	.165	1975

Near ambient concentration of 300 ppm CO₂ was used as a base line.

Results

Results of the test show that interference of SO_2 concentrations does occur with variation of CO_2 concentrations. This interference takes place over the range of CO_2 concentrations normally found during the indoor/outdoor air sampling program. The magnitude of the interference is shown in Figure 45 where the relationship between resulting SO_2 concentrations and increases in CO_2 levels are plotted on semi-log paper.

Correction Factor

Excellent correlations between all four tests permitted the development of a mathematical correction factor. The following equation can be applied to convert field SO_2 concentrations to SO_2 concentration at zero CO_2 levels provided CO_2 concentration present in the air sample is known during sampling. Throughout the entire study the SO_2 analyzer was calibrated with SO_2 containing zero CO_2 .

A = concentration of CO_2 (ppm)

B = reported concentration of SO_2 (ppm)

C = true concentration of SO_2 (ppm)

$$\ln C = \ln B + .000425 A$$

$$C = C^{\ln c}$$

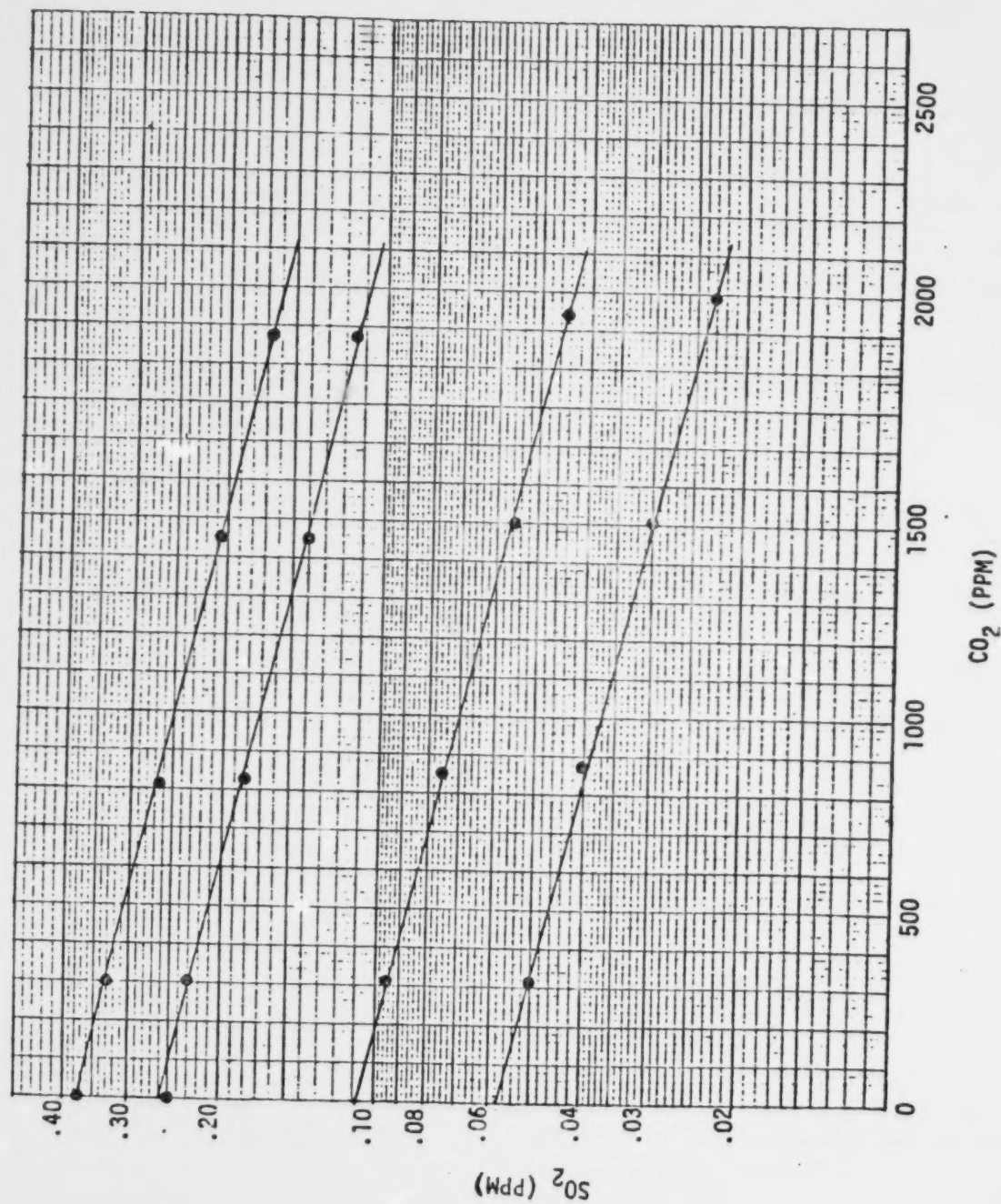


Figure 45. Relative change in SO₂ concentration with increase in CO₂ concentrations.

SPECIFICATIONS

NOTE: Use of this analyzer under EPA designation as an Equivalent Method requires operation on the 0.5 ppm full scale range within a temperature range of 20 ° - 30 °C and line voltage range of 105 to 125 V a.c.

Analyzer Performance Specifications*

Range:	0-0.5 ppm
Noise (RMS) 0% URL:	0.002 ppm
80% URL:	0.003 ppm
Minimum Detectable Limit:	0.004 ppm
Interference Equivalent:	+ 0.02 ppm each inter-ferent max. 0.06 ppm total inter-ferent max.
Zero Drift: (12 and 24 h)	+ 0.005 ppm
Span Drift: 20% of URL: (24 h) 80% of URL:	+ 10% max. + 5% max.
Lag Time:	10 s max.
Rise Time (95%):	3 min max.
Fall Time (95%):	3 min max.
Precision: 20% of URL: 80% of URL:	0.005 ppm 0.005 ppm
Linearity: a) With Linearizer Output (Option S-1)	+ 1% Full Scale
b) Without Linearizer Output (Log-Linear Output)	+ 1% Full Scale

*The definition and the method of determination of these specifications are given in 40 CFR 53 and the Federal Register (1975).

Analyzer Operational Specifications

Unattended Operation: (No adjustment of flow or electrical systems)	7 d
Sample Flow Rate:	Approx. 200 ml/min
Hydrogen Flow Rate:	Approx. 125 ml/min
Outputs: (Linear with Option S-1; Log-linear without option)	a) Meter: 0-0.5 ppm b) Recorder: 0-100 mV 0-1 V
Relative Humidity Range:	0-95%
Ambient Temperature Range:	20 ° to 30 °C (EPA approved), 10 ° to 40 °C*
Voltage Range:	115 $\pm$ 10 V a.c., 60 Hz
Power Requirements:	250 W

Analyzer Configuration Specifications

Weight:	18 to 22 kg (40 to 50 lbs) depending on options included
Case Dimensions:	43.2 cm (17 in.)W x 50.8 cm (20 in.)L x 31.1 cm (12-1/4 in.)H
Mountings Available:	a) Bench b) Rack (optional), 48 cm (19 in.) wide
Sample Pump:	Internal

*Use of this analyzer under EPA designation as a reference method requires operation within a temperature range of 20 ° to 30 °C and 105 to 125 V a.c. However, the analyzer will operate over 10 ° to 40 °C with only a small increase in the noise, precision, and drift specifications stated.

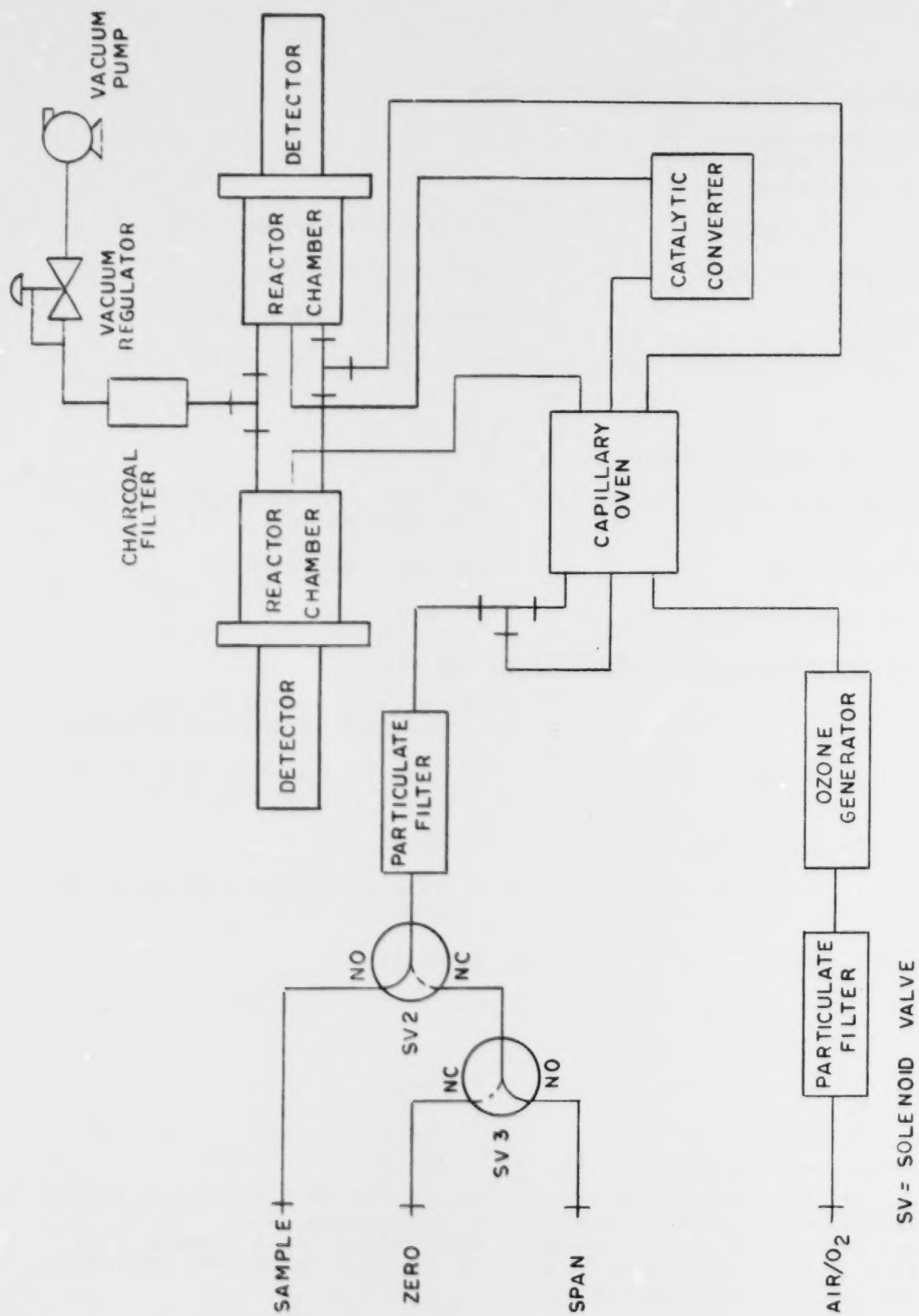


Figure 46. Pneumatic flow diagram of the chemiluminizer.

H₂S SCRUBBER SPECIFICATIONS

Life:	a) In excess of 9000 h at typical ambient H ₂ S level of 5 ppb. b) In excess of 450 h for H ₂ S concentration levels not exceeding 0.1 ppm.
Scrubbing Efficiency:	98% H ₂ S while passing 98% or greater SO ₂ .
Sample Lines:	3.175 mm (0.125 in.) o.d. Teflon Tubing
Size:	10 cm (4 in.) L x 1.6 cm (0.625 in.) i.d.

THC/Methane

The (MSA) Mine Safety Appliance Co. THC/Methane Analyzer Model 11-2 is used to continuously register levels of both pollutants. This dual Hydrogen Flame Ionization Detector is designed to continuously and simultaneously analyze ambient air for methane and total hydrocarbons minus methane. A dual flame head is closely coupled with individual electrometers whose output is directed to an electronic system to obtain continuous individual signals for the two measurements. An equal output signal is set on each electrometer output. The sample containing hydrocarbons including methane is fed by a self-contained pump to a parallel inlet system (see Figure 47). Burner #1 is fed the unaltered sample. In Burner #2, the sample is passed through a cutter catalyst bed. The catalyst oxidizes all hydrocarbons except

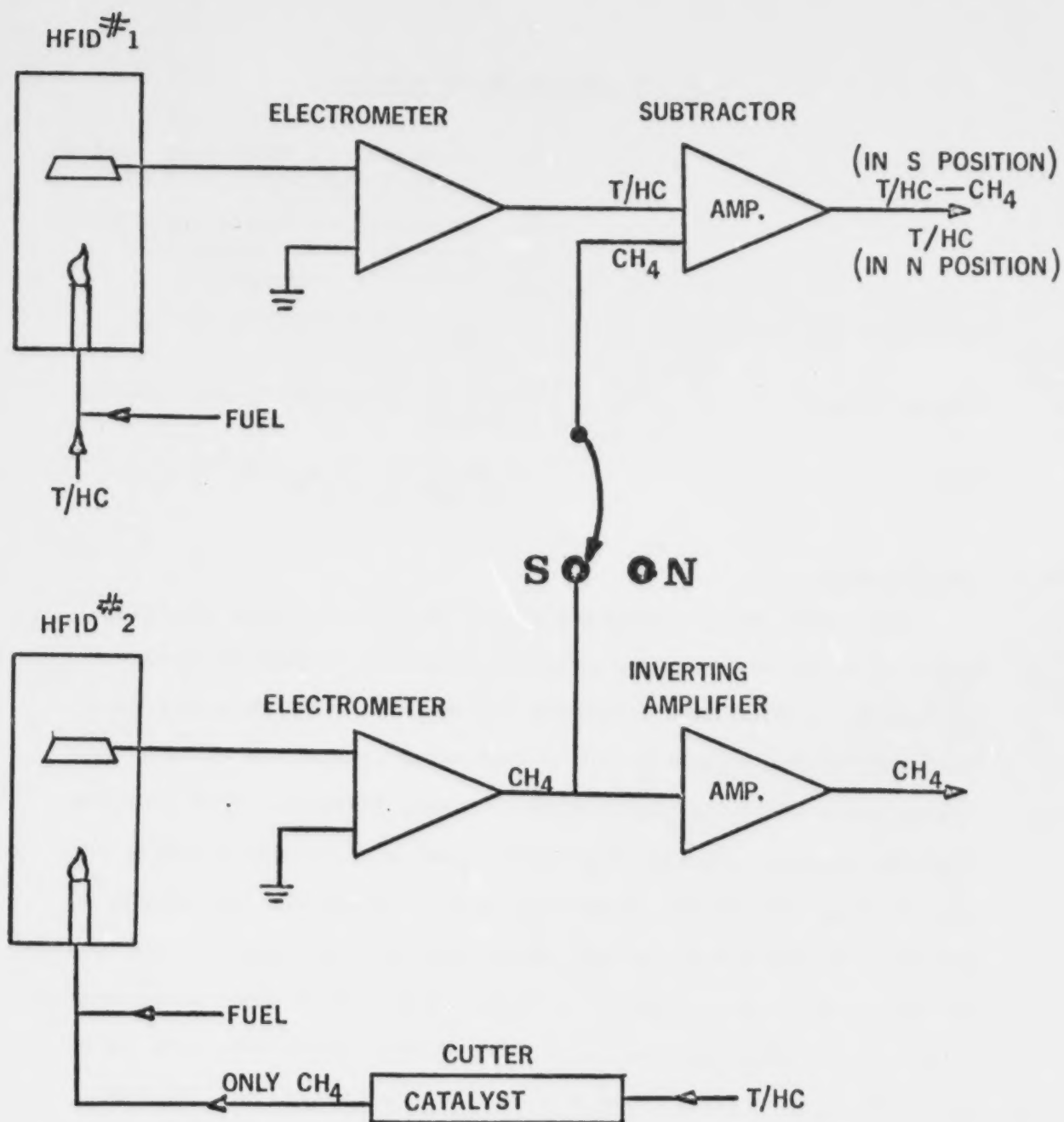


Figure 47. Schematic diagram of THC/Methane analyzer.

methane. More than 99% of all other hydrocarbons is removed, while methane passes through unaltered. Thus, one burner detects all hydrocarbons including methane, while the other burner detects only methane. By electronic subtraction the output signals then indicate total hydrocarbons, less methane, through Burner #1, and methane only through Burner #2.

SPECIFICATIONS

Accuracy/Reproducibility:	+1% of full scale
Speed of Response:	15 s for 100% of final reading
Noise Level:	+0.5% of full scale
Zero Stability/Drift:	+1% of full scale in - 24 h
Span Stability/Drift:	+1% of full scale in - 24 h
Linearity:	Less than 1% of full scale (measured at mid-scale) for both ranges
Sample Flow Rate:	10 cm ³ /min/burner
Fuel Flow Rate:	100% hydrogen, approximately 20 cm ³ /min/burner
Sample Treatment Range:	4.44 ° - 43.33 ° C (40 ° - 110 ° F)
Ambient Operating Range:	4.44 ° - 43.33 ° C (40 ° - 110 ° F)
Warm-up Time	4 h
Dimensions:	83.8 cm (33 in.)H x 50.8 cm (20 in.)W x 33 cm (13 in.)i.d.
Weight/Analyzer: Shipping:	Analyzer 27.2 kg (60 lb); shipping 54.4 kg (120 lb)

SPECIAL TEST TO DETERMINE EFFECTS OF LONG SAMPLING LINES ON AIR SAMPLING CONDUCTED DURING INDOOR/OUTDOOR AIR MONITORING PROGRAM

Prior to the start-up of the indoor/outdoor air sampling program, concern was expressed that long lengths of sampling line might cause decreases in concentrations of certain pollutants. To determine if any decreases might occur and to what extent, a series of three special tests was conducted. These tests were conducted at the beginning, midway and at the end of the useful life of the sample line.

- ° Special Test No. 1 was conducted prior to the sampling program. The effect of long and short sampling lines on O_3 and SO_2 concentrations was compared.
- ° Special Test No. 2 was conducted under actual sampling conditions. A comparison of long and short sampling lines on all pollutants continuously measured was made.
- ° Special Test No. 3 was conducted on a used sample line that had been replaced. A comparison of a new short sample line and a long sample line, in use for 11 mo, on SO_2 , NO, and NO_x pollutants was made.

RESULTS

Tests results indicate that when an air sample is pulled through 65 to 100 ft length of 3/8 in. Teflon sample line at a rate of 13 liters per min, the concentration of pollutants in the air sample are not decreased or changed. A slight decrease of 0.001 ppm SO_2 was observed with a 100 ft section of sample

line used for 11 mo, as compared to a 10 ft section of new sample line.

- ° Special Test No. 1 showed that long lengths of new Teflon sample line had no effect on the concentrations of O_3 and SO_2 samples.
- ° Special Test No. 2 showed slight changes between readings caused by changes in ambient concentrations during the 35 min test period. This trend was noted for all pollutants. None of the pollutants measured showed differences between 20 ft and 100 ft sampling lines.
- ° Special Test No. 3 showed slight decreases in SO_2 and NO_x concentrations between the new 10 ft sample line and the old 100 ft sample line. SO_2 decrease was 0.001 ppm at a concentration of 0.02² ppm. NO_x changes observed (-0.002 ppm) are possibly due to instrument noise.

Descriptions of individual test procedures and all test results are presented on the following pages.

Special Test No. 1 - Possible decrease in pollutant concentrations by long sample lines.

Prior to the start-up of the indoor/outdoor air sampling program, a special test was conducted to determine if concentrations of O_3 and SO_2 would be decreased when air samples passed through lengths of 3/8 in. Teflon sample lines. Tests were conducted using the same sampling system that was to be used through the sampling program (Figure 48).

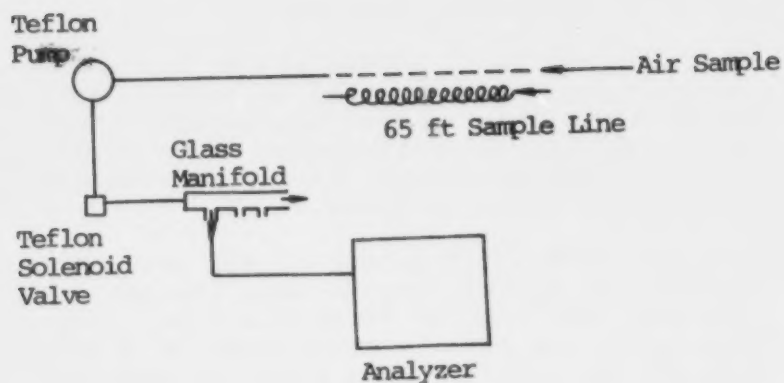
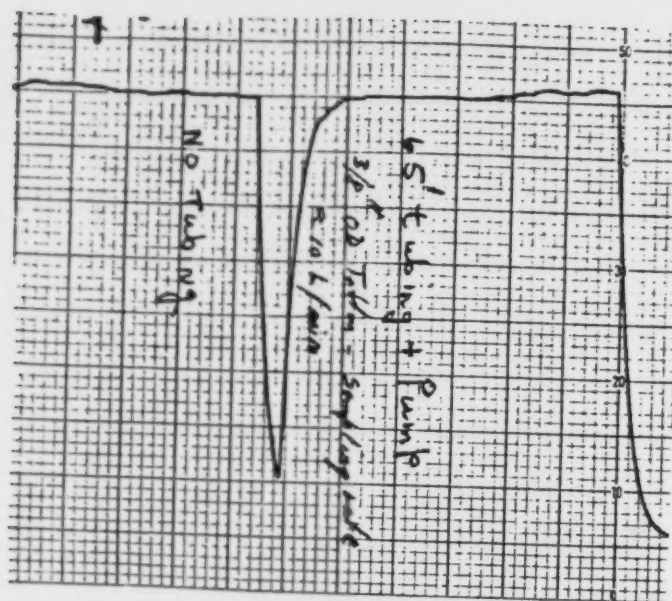
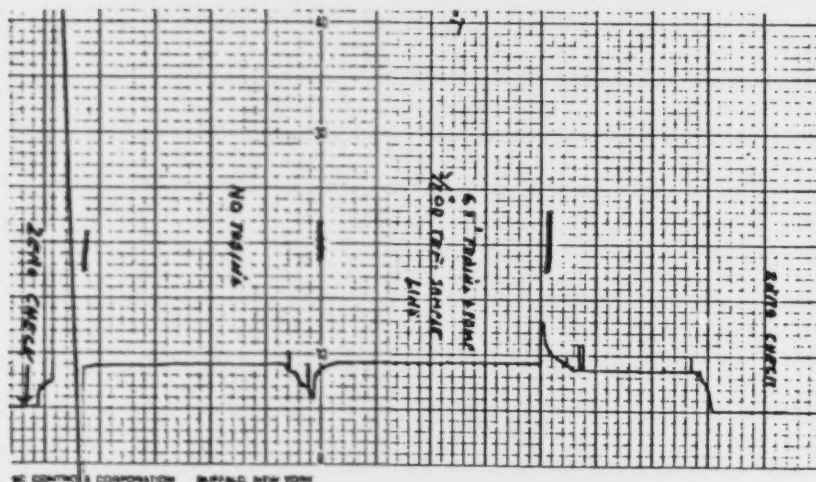


Figure 48. Special Test No. 1 equipment set-up.

Sample concentrations of each pollutant were generated and passed through the sampling system. The analyzer sampling line was attached to the manifold and a sample was taken until a stable trace was recorded. A 65 ft length of the sample line was then placed in series between the source and the pump and the resulting trace recorded. Reproductions of the resulting strip charts are shown in Figures 49 - 53. A summary of the results obtained is presented in Table 3.

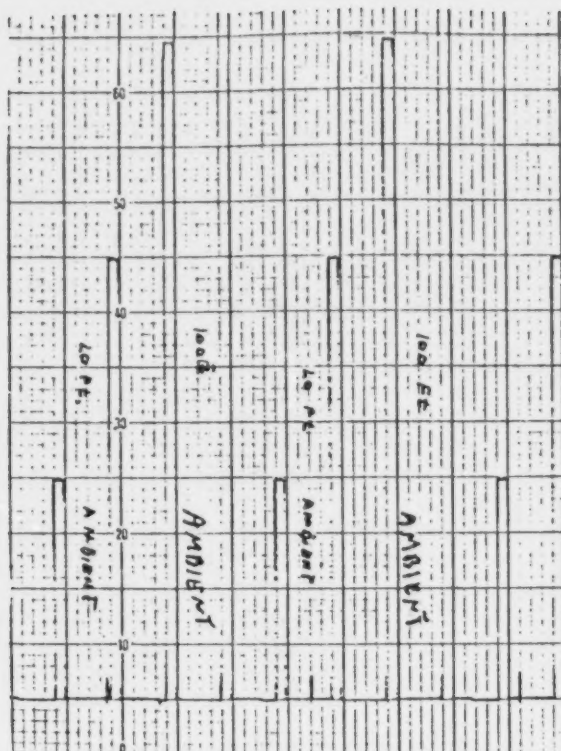


O₃ comparison chart

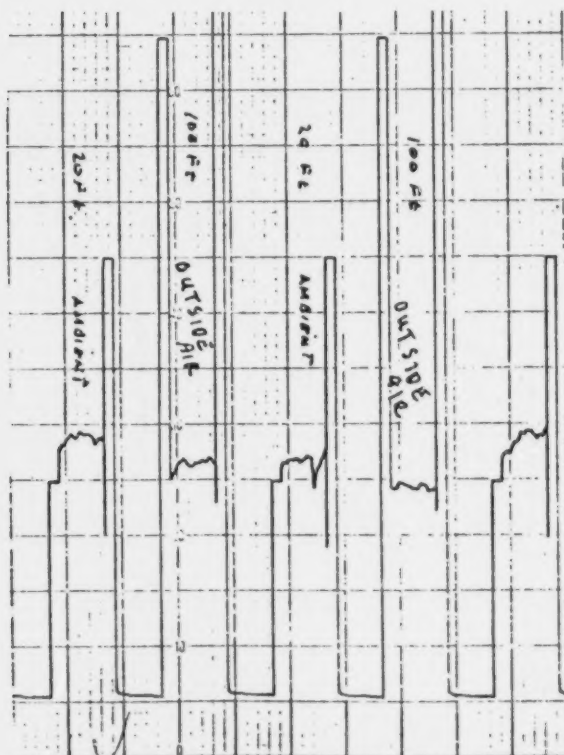


SO₂ comparison chart

Figure 49. O₃ and SO₂ comparison charts from Special Test No. 1.

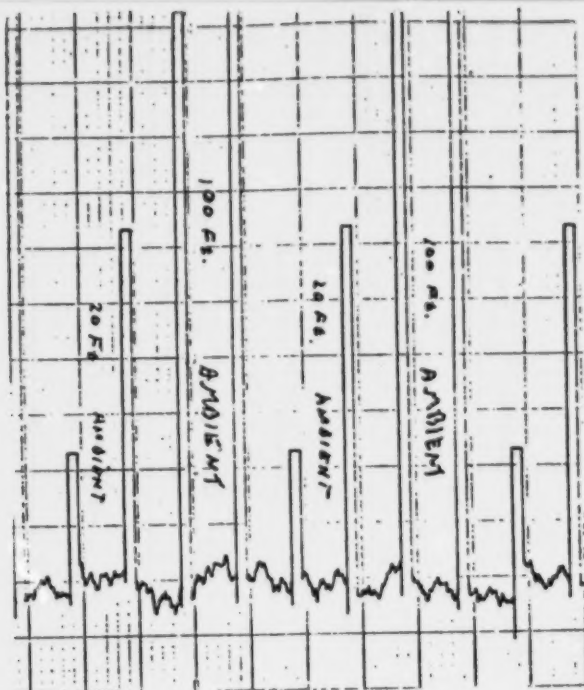


SO₂ comparison chart

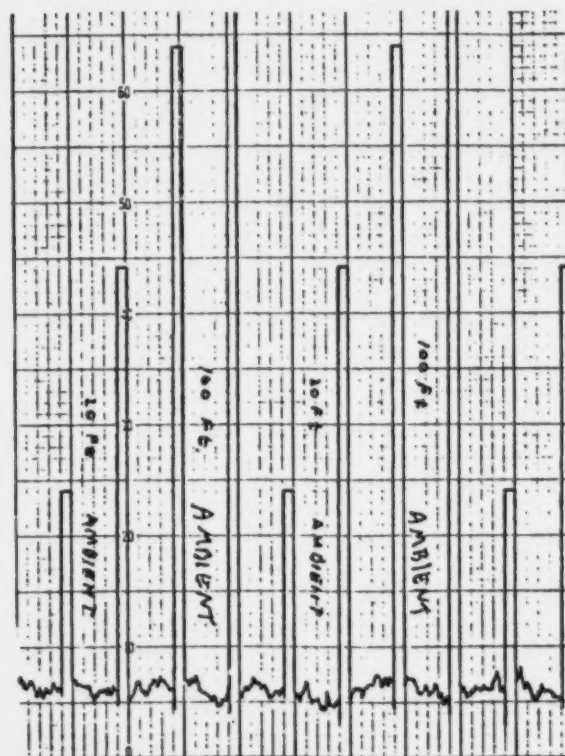


O₃ comparison chart

Figure 50. SO₂ and O₃ comparison charts from Special Test No. 2.



NO_x comparison chart



NO comparison chart

Figure 51. NO_x and NO comparison charts from Special Test No. 2.

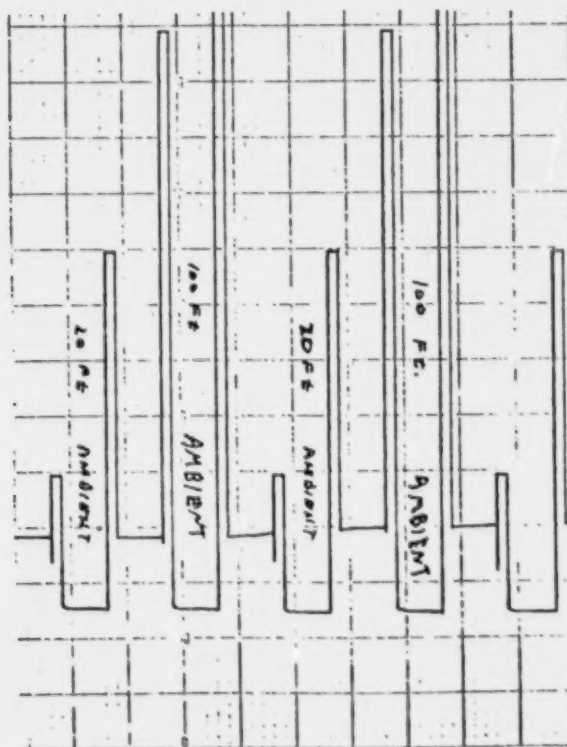
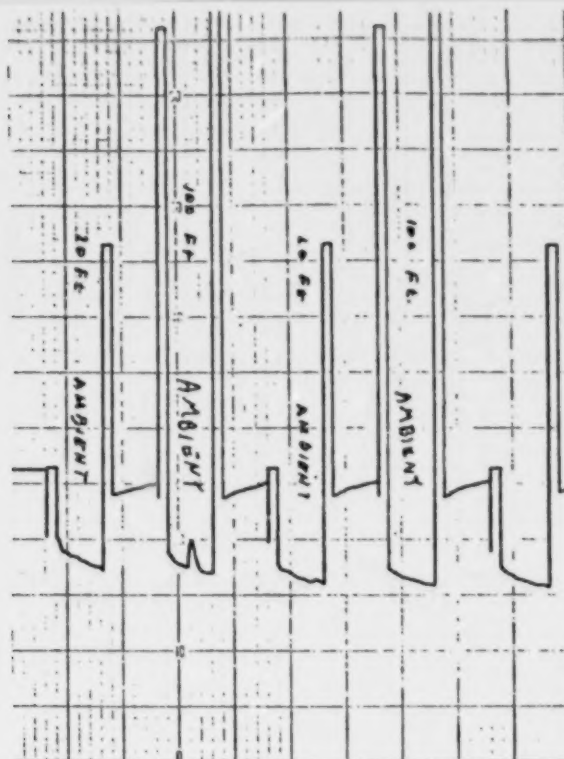


Figure 52. THC and CH₄ comparison charts from Special Test No. 2.

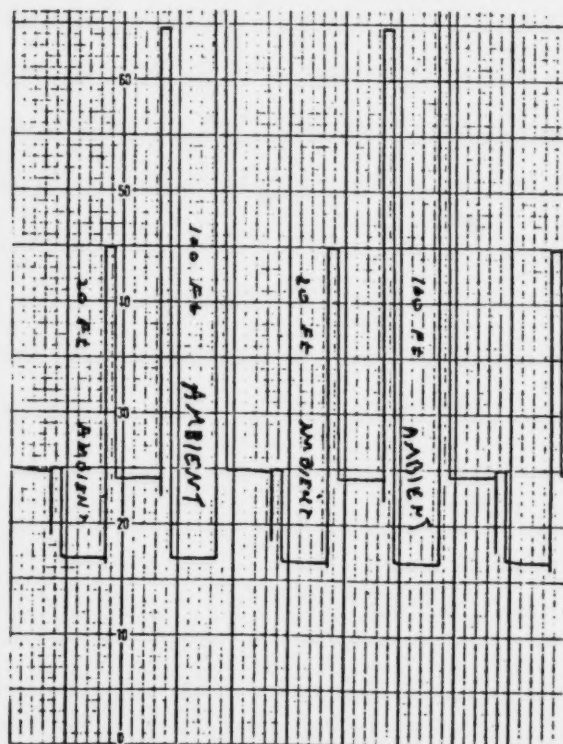
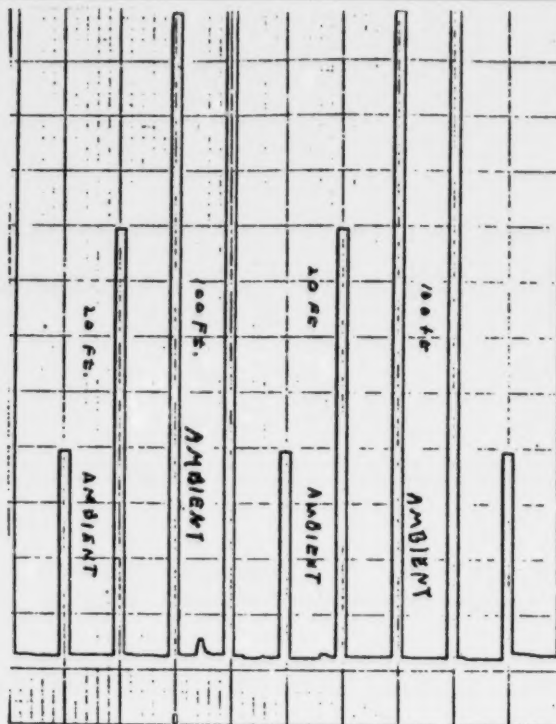


Figure 53. CO and CO₂ comparison charts from Special Test No. 2.

TABLE 3. RESULTS OF SPECIAL TEST NO. 1

Length of line	O ₃ (ppm)	SO ₂ (ppm)
1 ft	0.200	0.02
65 ft	0.200	0.02

Special Test No. 2 - Possible decrease in pollutant concentrations by long sample lines.

A second special test was conducted to determine if concentrations of pollutants measured would be reduced when passing through long lengths of sample line under actual sampling conditions. The two sampling lines compared were the 20 ft ambient sample line and the 100 ft bedroom sample line. Tests were conducted by removing the bedroom line from indoors and allowing it to sample ambient air. Reproductions of the resulting strip charts were shown in Figures 50, 51, 52, and 53. A summary of the results obtained is presented in Table 4. Slight changes in concentrations obtained are due to the change in ambient concentrations over the 35 min test period.

TABLE 4. RESULTS OF SPECIAL TEST NO. 2

Pollutant (ppm)	Length of sample line			
	20 ft	100 ft	20 ft	100 ft
SO ₂	0	0	0	0
O ₃	0.120	0.108	0.108	0.098
NO _x	0.025	0.030	0.023	0.020
NO	0.005	0.005	0.002	0.005
THC	5.2	5.2	4.6	4.6
CH ₄	3.12	3.12	2.90	2.90
CO	0.65	0.65	0.60	0.60
CO ₂	300	300	293	293

Special Test No. 3 - Possible decrease in pollutant concentrations by long sample lines.

A third special test was conducted to determine if concentrations of SO₂, NO or NO_x were reduced when passing through long lengths of 3/8 in. Teflon sampling line (see Figure 54). For test purposes, a new 10 ft section of sampling line was compared to a 100 ft section of sampling line which had been in use for the previous 11 mo and had been replaced.

The following equipment set-up was used in conducting comparison tests:

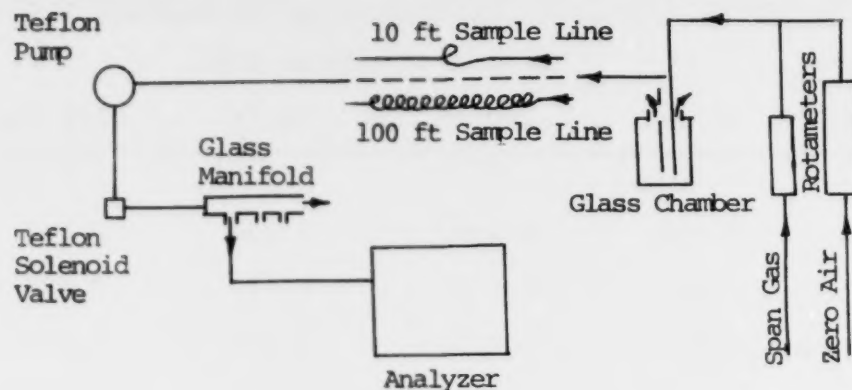
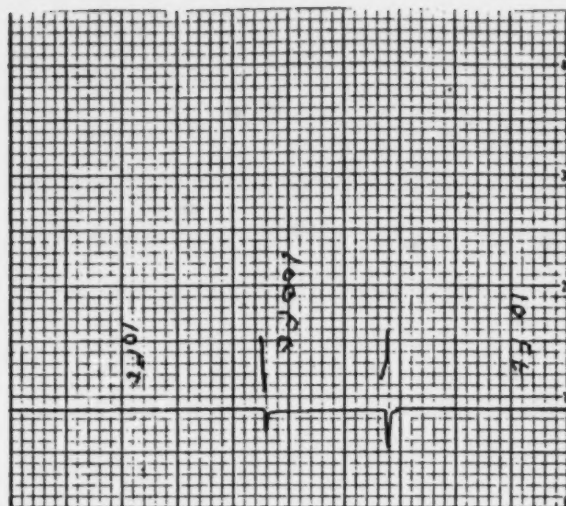


Figure 54. Special Test No. 3 equipment set-up.

Test procedure was to reduce the concentration of the span gas to the desired concentration by dilution with 20 liters of zero air. The test gas passed into the glass mixing chamber; then a sample was removed at a rate of 3 liters per min from the chamber through the test sample line by the pump and exhausted through the solenoid valve and manifold. In this way, the air sample passed from the source to the analyzer in the same manner as under normal sampling conditions. After the desired concentration was generated, the two lengths of sample line were alternated. Results of this test are shown in Figure 55.

TABLE 5. RESULTS OF SPECIAL TEST NO. 3

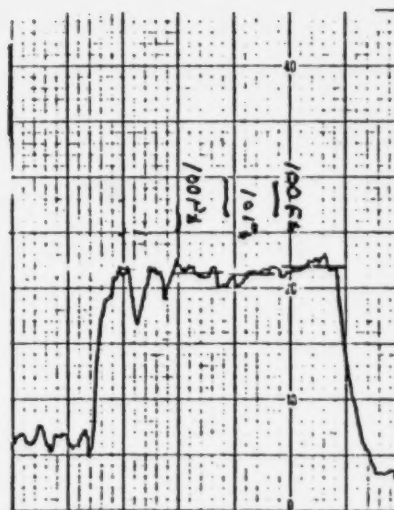
Length of line	SO ₂ (ppm)	NO (ppm)	NO _x (ppm)
10 ft	.020	.083	.097
100 ft	.019	.083	.095



SO₂ comparison chart



NO_x comparison chart



NO comparison chart

Figure 55. Results of comparison test from Special Test No. 3.

Wind Speed/Direction

The Bendix Aerovane Wind Transmitter, Model 120, which is a dual-purpose instrument for measuring wind speed and wind direction, was used. The transmitter is 76.2 cm (30 in.) long, weighs approximately 5.9 kg (13 lb), and is designed to be mounted on a support tower as described. The system operates on 115 V a.c., 60 Hz power and does not emit radio frequency interference.

Wind speed is measured by a three-bladed impeller fastened to the armature of a tachometer magneto located in the nose of the instrument. The speed or rotation is directly proportional to the speed of the wind striking the impeller blades; thus, the voltage generated by the magneto is a function of wind speed. This voltage is electrically transmitted to a remotely located voltmeter which is calibrated to indicate wind speed in terms of knots or miles per hour for immediate visual observation. Electrical output into 1150 ohm load is:

0.1056 V d.c. per mi/h

0.1215 V d.c. per knot

0.0656 V d.c. per km/h

Wind direction is measured by a streamlined vane, coupled to the rotor of a type 1 HC synchro. This synchro electrically transmits the vane position to a remotely located companion synchro which interfaces with the data collection system.

Temperature-Relative Humidity

Weather Measure H-311 Hygrothermograph--

This instrument is built to meet professional meteorological and industrial needs. The instrument can be used either indoors or outdoors. When used outdoors, the instrument is normally placed in a louvered shelter or under a thermal screen to eliminate the effects of solar radiation.

The Model H-311 utilizes a bimetallic strip for temperature measurements and a human hair bundle for relative humidity measurements.

Temperature and relative humidity are recorded simultaneously on a 17.8 cm (7-in.) chart mounted on a clock drive drum. Temperature is recorded on the upper half of the chart; relative humidity is recorded on the lower half.

A combination 1-d/7-d and a 31-d chart drive--both spring wound and electric--can be provided. The 1-d/7-d clock comes factory-equipped with two gears, one for each chart speed. No external power is required to operate this instrument.

All major internal components are chrome-plated brass; pivots are stainless steel; the instrument base is an aluminum alloy, and the case is steel. Openings in the sides and end of the case allow free movement of air to the sensing elements.

The temperature-sensing element is a curved bimetal strip that has been properly aged to remove internal stresses. One end of the strip is attached to the instrument base, and the

other end is attached to the pen arm linkage. Temperature variations deflect the bimetal strip to an expanded or contracted position that is directly proportional to the temperature. These changes are translated to the pen arm through mechanical linkage. Temperature measurements may be made over a total span of 43.3 °C (110 °F). The span may be adjusted upward or downward to cover a 43.3 °C (110 °F) range of common interest in meteorological sciences.

Relative humidity is measured by means of a bundle of human hair attached securely to the case at both ends and looped through the pen linkage. Changes in relative humidity cause the hair to expand and contract, thereby moving the pen arm linkage.

The length of hair increases by about 2-2.5% when the relative humidity changes from 0-100%. Since human hair has a nonlinear response to changes in humidity, this is compensated for by the use of two opposed quadrants to provide linear response to the pen arm. For relative humidities above 20%, the elongation is approximately proportional to the logarithm of the relative humidity.

The response of any given hair to fluctuations in humidity is not as simple as the response of a thermometer to changes in temperature. It is found that the ratio $(du/dt)/(U-U_f)$, where U is the instantaneous indicated humidity, and U_f the final or true value of the humidity, is not a constant for a given

instrument. Variations depend not only on the ventilation, but also on the actual indicated humidity U, temperature, positive or negative value of dU/dt , tension of the hair, and previous treatment of the hair.

SPECIFICATIONS

Temperature Sensor:

Range:	37.8 °C (100 °F) (adjustable)
Sensor:	Aged bimetallic strip
Temperature Scale:	-20 °C to +40 °C, +10 °F to +120 °F or -30 °F to +80 °F (can be adjusted to any 110 °F range of interest in meteorological sciences)
Accuracy:	<u>+1%</u>
Chart Scale Divisions:	1 °C or 2 °F

Humidity Sensor:

Range:	0 to 100%
Sensor:	Human hair bundle
Accuracy:	+1% between 20 and 80%, approximately 3% at extremes
Sensitivity:	Less than 1%
Chart Scale Divisions:	1%

General:

Chart Size:	17.8 cm (7 in.)H x 29.2 cm (11.5 in.)L
Chart Drive:	1-1/2V d.c. or spring wound
Drum Rotation:	1-d/7-d, or 31-d
Size:	31.75 cm (12.5 in.)L x 29.2 cm (11.5 in.)H x 15.2 cm (6 in.)W
Weight:	4.87 kg (10.75 lb)

Energy Consumption Measurements

Total Power Consumption Measurements--

Measurement of the total energy consumption were made by employing two recording ammeters. Each ammeter was connected such that both ungrounded legs of the power lines to the house were monitored. The instrument range normally employed for this measurement is 0-50 A; however, during the winter heating season, often a 0-250 A range is employed. The recording ammeter chart has five 12-min divisions per hour. The average percent chart deflection for each 12-min period was estimated for each strip chart, and five 12-min periods were added together for each hour. This average percent chart was then multiplied by the instrument range, which resulted in the average current reading per hour. The average current reading per hour was then multiplied by the voltage of the ungrounded line. A figure of 120 V was used since this is the nominal line voltage for residential use. The net result was watt-hours. Kilowatt-hours ($\frac{\text{watts}}{1000}$) were reported for each hour.

In addition to the above measurement, daily readings of the electric watt-hour meter were made. These data are reported in

kilowatt-hours per day and is normally measured from 1600 to 1600 each day. The primary purpose of these data was to provide a daily quality control check for the ammeter measurements.

Heating and Air Conditioning Measurements--

Four basic types of furnace measurements were made; they are:

- ° Electric Furnace

For an electric furnace, the current was monitored with the recording ammeter. This ammeter was connected to the power line of the resistance coil. Should more than one resistance coil be employed within the furnace, and if they were wired separately, the current of each line was monitored. Since all electric home heating units are 240 V, only one of the two ungrounded 240-V lines was monitored. The average percent chart from each recording ammeter was determined for each hour, added together, multiplied by 2 to account for the 240 V supply, then multiplied by the ammeter range to obtain kilowatt-hours. Kilowatt-hours are reported.

- ° Heat Pumps and Air Conditioners

Energy consumption for heat pumps and air conditioners was monitored the same, with the exception that heat pumps normally have auxiliary resistance coils. The energy consumption for these coils was monitored as described for the electric furnace. A heat pump or central air conditioner was monitored employing a recording ammeter on one leg of the 240-V supply line. The calculations to obtain kilowatt-hours are the same as described above for the electric resistance furnace.

- ° Oil Furnaces

To determine the hourly consumption of heating oil, a recording ammeter was attached to one leg of the 120-V power line of the furnace oil pump. Each time the pump was activated, the duration of its on-time was recorded on the recording ammeter. The oil pumping time per hour was determined from this recording. This time was then multiplied by the pump rate specification which was supplied by the furnace manufacturer to obtain the volume of oil consumed per hour. A daily measurement of the oil consumption was made by measuring the volume of the oil tank and the daily replacement employing a dip stick. This measurement was used as a quality control check for the hourly measurements.

° Gas Furnaces

Gas consumption rates from gas furnaces were monitored by employing a recording ammeter on the furnace blower. This recorded results only in the time duration the blower was on per hour. The thermostat was set at a fixed temperature setting during the study and the furnace operated on the following cycle:

1. Gas ignited to heat furnace bonnet to a set temperature (time for this activity was measured and was constant for each cycle).
2. When the bonnet blower reached its proper temperature, the activated recording ammeter measurement began.
3. Gas combustion continued until the thermostat reached desired temperature, then the gas valve was electrically closed.
4. Blower continued to operate until the furnace bonnet cooled to a predetermined temperature, then the blower was deactivated. This portion of the time cycle was measured and was constant. The gas consumption per minute, while the furnace was in operation, was read from the gas meter.

From the above data, the gas usage per hour was calculated. Electrical consumption for air conditioning was monitored as described above.

INTERMITTENT SAMPLING

Intermittent sampling techniques and their related analytical methodology as employed for the measurement of indoor-outdoor pollutants are presented in Table 6. A detailed discussion of the indoor sampling and analytical techniques is given in the following subsections.

TABLE 6. INTERMITTENT SAMPLING AND ANALYTICAL METHODOLOGY
FOR INDOOR-OUTDOOR POLLUTANT MONITORING

Pollutant	Sampling rate (l/min)	Sampling period (h)	Analytical Method	Limit of detection (working)
Total suspended particulates	100	24	Filtration/gravimetric	0.1 $\mu\text{g}/\text{m}^3$
Respirable par- ticulates (3.5 μm)	50	24	Dochotomous/gravimetric	0.1 $\mu\text{g}/\text{m}^3$
Organic vapors	0.2	24	Charcoal absorption/gas chromatography	ppb as CH_4
Aliphatic aldehydes	0.5	4*	Bubbler/WBTH	1.5 $\mu\text{g}/\text{m}^3$
Ammonia	0.5	1	Bubbler/phenate	5 $\mu\text{g}/\text{m}^3$
Sulfates from TSP samples	100	24	Filtration/methyl- thymol blue	0.5 $\mu\text{g}/\text{m}^3$
Nitrates from TSP samples	100	24	Filtration/brucine	0.1 $\mu\text{g}/\text{m}^3$
Lead from TSP samples	100	24†	Filtration/atomic absorption	0.005 $\mu\text{g}/\text{m}^3$
Elemental analysis atomic No. 16 through 35 plus No. 82	1	Continuous	Streaker sampler/PXE	ppb to ppt

*The three indoor sampling lines sample for 4 h, the ambient coupline line samples for 24 h.

†Lead analysis is performed on 25% of the samples collected.

Total Suspended Particulates (TSP)

TSP were collected on 47-mm glass fiber filter material for a period of 24 h at a sampling rate of 84-112 l/min (3-4 ft³/min). The filters were initially equilibrated at 25 °C and 40% RH for 24 h prior to weighing to the nearest 0.01 mg. After sampling the filters were removed from their holders, equilibrated for 24 h, and weighed. The filters were then placed into petri dishes, sealed, and shipped to the PEDCo Lab in Cincinnati for chemical analysis of nitrate and sulfate.

SAMPLING PROCEDURE

1. Inspect new equilibrated filter for creases, holes, etc. which could affect its ability to collect particulate material (Note: Do not touch filters with fingers, use tweezers).
2. Record the filter number on the Intermittent Data Sheet.
3. Weigh and record the filter weight to the nearest 0.01 mg on the Intermittent Data Sheet.
4. Place the filter in its appropriate filter holder and record its location on the Intermittent Data Sheet.
5. Record the initial air volume and barometric pressure on the Intermittent Data Sheet.
6. Activate pump and record the initial time and the exit gas temperature after 15 min of sampling on the Intermittent Data Sheet.
7. Repeat steps 1 through 6 for the other three sampling locations.
8. After 24 h of sampling, turn off pump and record the final time, the final air volume, and the temperature of exit gas from dry gas meter on the Intermittent Data Sheet.

9. Remove the filter from its holder and place it into a plastic petri dish. Put the sample, with the petri dish lid removed, into the constant humidity equilibration chamber.
10. After 24 h of equilibration, weigh samples to the nearest 0.01 mg and record the weight on the Intermittent Data Sheet.
11. Place filter in plastic petri dish, seal and return the filter and data sheet to the PEDCo Laboratory for chemical analysis.
12. Calculate the total suspended particulate concentration as follows:

$$\text{TSP } (\mu\text{g}/\text{m}^3) = \frac{A}{B}$$

where:

A = μg of particulate (mg x 1000 = μg)

B = air volume (m^3)

$$\text{m}^3 = 0.02832 \left[\text{ft}^3 \times \frac{\text{Atmos. pressure}}{760 \text{ mm Hg}} \times \frac{298 \text{ K}}{\text{meter temperature}^* + 273} \right]$$

* use average meter temperature = initial temperature + final temperature/2

13. Record TSP concentrations on the appropriate 24-h sampling interval Computer Load Sheet.
14. Repeat steps 8 through 13 for each of the other three total suspended particulate samplers.

Particle Size

The Environmental Research Corporation (ERC) Model 200 Dichotomous Sampler is designed to sample airborne particles and classify them into two size fractons. The heart of the sampler is a two-stage virtual impactor whose principle of operation is analogous to that of an inertial impactor, however, the problems of particle bounce and shattering are

eliminated. Particles above the cut-point size flow directly through nozzles of two stages and are collected on a filter at a rate one-fiftieth of the sampling flow rate. The major fraction of the air is deflected around the nozzles of each stage and flows through a second filter where the particles smaller than the 50% cut-point of the sampler are collected. The primary advantage of the sampler is that the particles are uniformly deposited on low mass filters, which is most suitable for the assessment of their mass and chemical composition. The dichotomous sampler can be run continuously between changes of filter. The sampler is also supplied with a third filter for filtering the total aerosols without size fractionation.

SPECIFICATIONS

Performance: See collection efficiency curve, Figure 56.

Flow Rate = 14 l/min through virtual
impactor
14 l/min through total aerosol
filter

50% Cut-Point: 2.5 μ m, mmd
Concentration Ratio = 50:1

Filters: 37 mm

Power Requirement: 115 V a.c., 60 Hz, 1/4 HP

Dimensions: 27.9 cm (11 in.) x 71 cm (28 in.)
x 45.7 cm (18 in.) (subject to change)

Shipping Weight: 27.2 kg (60 lb)

Options: Other flow rates and cut-points are
available.

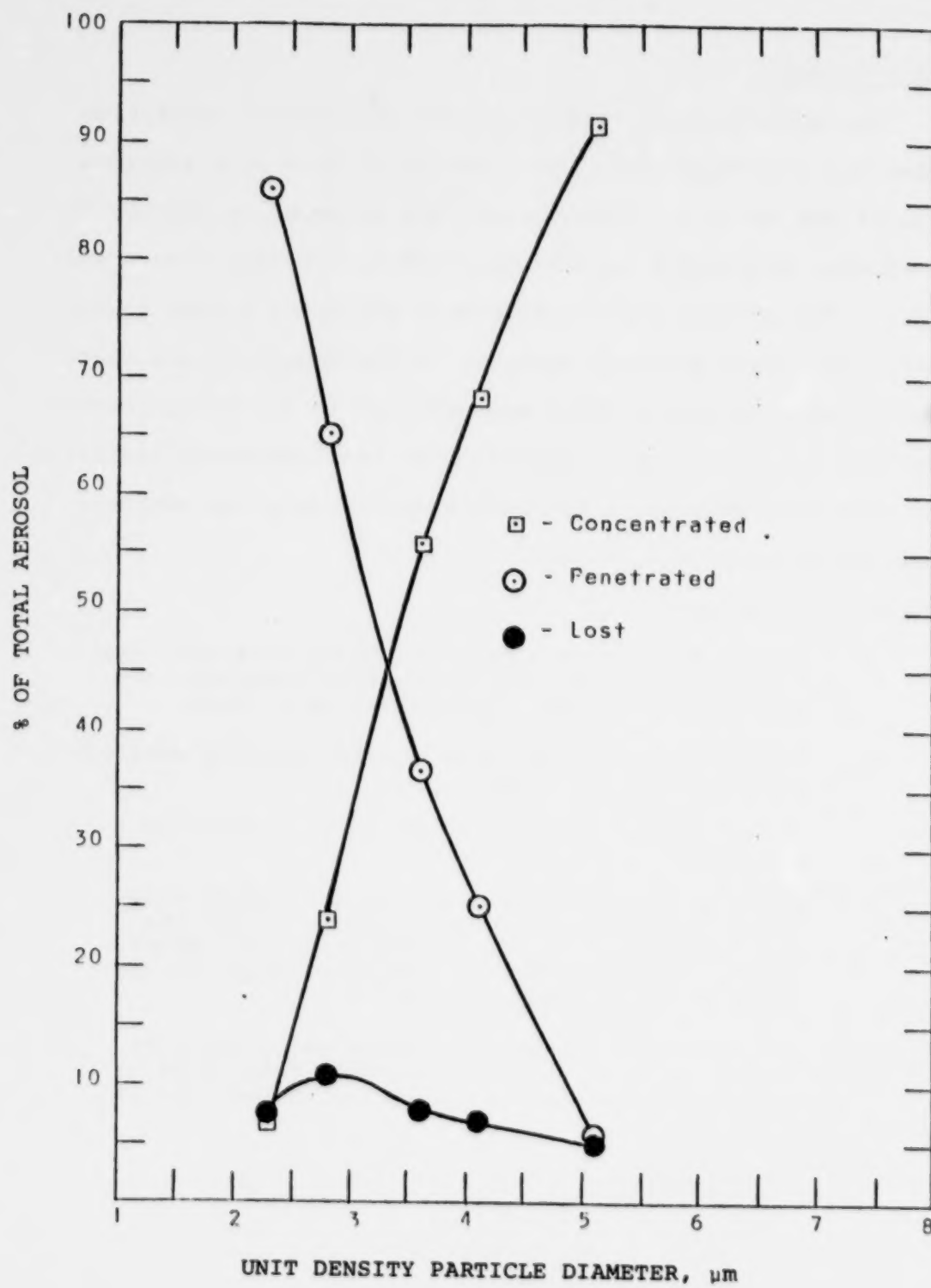


Figure 56. Collection efficiency curve for dichotomous sampler.

Organic Vapors

The collection of organic vapors on charcoal absorption tubes was conducted daily for a period of 24 h at a sampling rate of 200 cm³/min. Flow control was achieved by the use of calibrated hypodermic needles operated at critical flow conditions. The needles were recalibrated employing a soap bubble meter after each sampling session. After sampling, the charcoal tubes were refrigerated and returned to the PEDCo laboratory for analysis. Upon completion of the laboratory analysis, the data were entered on the 24-h sampling interval computer load sheets expressed in µg/m³.

Sampling Procedure--

1. Record date, tube number, sampling location, start time, start flow rate, barometric pressure, and temperature on the Intermittent Data Sheet.
2. Connect the charcoal tube to the sampling manifold and activate the pump.
3. Repeat Steps 1 and 2 for the other 3 sampling locations.
4. After 24 h of sampling, record the ending time, final flow rate, barometric pressure, and the temperature on the Intermittent Data Sheet. Remove the tube from the sampling manifold, and place it in the refrigerator.
5. Calibrate the hypodermic needle using the soap bubble meter and correct the flow rate to standard conditions using the following calculation:

$$Q_s^1 = Q_s \left[\frac{P_1}{760 \text{ mm Hg}} \times \frac{298 \text{ K}}{T_1 + 273 \text{ K}} \right]^{1/2}$$

where:

Qs^1 = flow rate corrected to standard conditions.

Qs = flow rate at field conditions.

P_1 = barometric pressure at field conditions (mm Hg).

T_1 = temperature at field conditions ($^{\circ}C$).

6. Repeat steps 4 and 5 for the other sampling locations.
7. After each 2-week sampling program, the charcoal tubes and data sheets are hand carried to the PEDCo Laboratory for analysis.

Analytical Procedures--

Gaseous organic materials in ambient air were collected and concentrated on activated carbon. After an adequate sampling period, the organic materials were desorbed using carbon disulfide. Aliquots of the carbon disulfide solution were injected into a gas chromatograph. Qualitative identification was determined by observing the retention times of discernible components and comparing them with known retention times of specific organics. Quantification was accomplished by comparison with known standards of the identified compounds.

Desorption--Fill a glass-stoppered graduated cylinder to the 25-ml mark with carbon disulfide. Stopper and cool in an ice bath. Remove the cap and glass wool plug from the carbon absorption tube and rapidly add the activated carbon to the carbon disulfide. Restopper the graduated cylinder and mix

thoroughly. Allow the mixture to stand for 30 min in the ice bath. Draw off the supernatant solution and completely fill a small vial (2 to 5 ml capacity).

Analysis--Precondition the chromatographic column according to recommended procedures. Adjust the carrier gas to the proper flow rate, and inject an aliquot of the sample (2.5 μ l) into the gas chromatograph. Mark the injection time on the recorder. From the recorder chart, calculate the retention times of all identifiable peaks. Compare against retention times of known organics for identification. Inject aliquots of the identified materials into the gas chromatograph to verify and

Calculation--

$$\mu\text{g}/\text{m}^3 = \frac{\mu\text{g}/\mu\text{l found} \cdot 25,000 \cdot 1,000}{F \cdot T}$$

where:

F = sampling flow rate in liters/minute

T = time of sampling in minutes

$$\text{ppm} = \frac{\mu\text{g}/\text{m}^3 \cdot 24.45}{1,000 \cdot \text{MW}}$$

where:

24.45 = liters occupied by one gram molecule at 25 °C and 760 mm Hg.

MW = molecular weight of identified compound.

Aliphatic Aldehydes

Aliphatic aldehydes in ambient air were collected in a 0.05% aqueous solution of 3-Methyl-2-benzothiazolone

hydrazone hydrochloride (MBTH). Aliphatic aldehydes react with MBTH in the presence of ferric chloride (FeCl_3) to form a blue cationic dye in an acidic medium which is measured at 628 nm. The blue color is stable for at least an hour, and a linear relationship is exhibited over the range of 0 to 10 $\mu\text{g/ml}$ of test solution thorough a 19 mm (0.75 in.) light path. Sampling was conducted daily during the following periods at the three inside locations:

4-h sample: 0600 - 1000

4-h sample: 1000 - 1400

4-h sample: 1600 - 2000.

At the fourth location ambient air was sampled for a 24-h period daily. Two impingers, operated in series at a flow rate of $500 \text{ cm}^3/\text{min}$, each containing 25 ml of absorbing reagent, were employed for the collection of the aliphatic aldehydes.

Equipment--

Spectrophotometer--Any instrument capable of measuring absorbance up to 700 nm is acceptable.

Impingers--Capacity of 75-100 ml with 40-70 μm porosity fritted bubblers (Corning coarse frit).

Air metering and flow control devices--Any device capable of measuring and regulating airflows with a $\pm 2\%$ accuracy is acceptable.

Air pump--Any pump capable of pulling air through a sampling train at a rate of 500 ml/min is acceptable.

Reagents--

Collecting solution, 0.05% MBTH--Dissolve 0.500 g 3-Methyl-2-benzothiazolone hydrazone hydrochloride (MBTH) in 900 ml distilled water in a 1-liter volumetric flask. Dilute to volume. If turbid, gravity filter through a fine retentive paper. The solution is stable for one week, but stability can be increased by storing in a dark bottle in a refrigerator.

Oxidizing reagent, 1.0% FeCl_3 in 1.6% sulfonic acid--Dissolve 8.0 g sulfamic acid in 400 ml distilled water in a 500-ml volumetric flask. Add 5.0 g FeCl_3 and dissolve. Dilute to volume with distilled water.

Dimedon--Dissolve 0.535 g 5,5-dimethylcyclohexane-dione-1,3 (Dimedon) in 200 ml distilled water in a 250-ml volumetric flask. Dilute to volume.

Formaldehyde solution, standardized--Dilute 2.7 ml of reagent grade 37-39% HCHO to a liter with distilled water. Into each of three stoppered 250 ml Erlenmeyer flasks containing 50 ml of Dimedon solution, add 10 ml of the aqueous formaldehyde solution. Shake the mixtures and allow to stand overnight or preferably over a weekend. Quantitatively transfer and filter through previously tared sintered glassed crucibles. Vacuum-dry over phosphorus pentoxide (P_2O_5) to constant weight. $\text{g/ml } 37\text{-}39\% \text{ HCHO} - \text{average weight of precipitate} \times 0.1027 \times 100/2.7$.

Sampling Procedure--

1. Add 25 ml of absorbing reagent to each bubbler tube.
2. Fill out the intermittent sampling record sheet as depicted in the example attached for each bubbler train.
3. Activate the bubbler train for the prescribed sampling period.
4. After sampling, record the stop time, transfer the sample from each bubbler tube into a sealed container, and stack in the refrigerator for analyses.
5. Rinse the bubblers with absorbing reagent and repeat sampling sequence with Step #1, according to the designated schedule.

Field Analysis--

1. Each day analyze all samples collected (both front and rear portions of the bubbler train).
2. Pipette 10 ml of each sample blank and standard saturators into 19 mm (0.75 in.) spectrophotometer cells.
3. Add 2 ml of the ferric chloride oxidizing reagent and mix well.
4. After 12 min but before 60 min, read and record the absorbance at 628 mm in the Field Analytical Log Book for each sample and standard employing the reagent blank for the spectrophotometer blank. Plot absorbance (ordinate) versus micrograms of formaldehyde (abscissa), and calculate the line of best fit.

Calculations--

$$1. \quad \text{Aldehydes as HCHO, ppm} = \frac{V \cdot C \cdot 24.45^*}{F \cdot T \cdot 30.04} + \frac{V \cdot C \cdot 24.45^{**}}{F \cdot T \cdot 30.04}$$

where:

V = total volume of collecting solution

C = $\mu\text{g/ml}$ of formaldehyde determined

F = sampling rate in liters/min

T = sampling time in minutes

30.40 = molecular weight of formaldehyde

24.45 = liters occupied by a gram molecular weight
at 20 °C and 760 mm Hg

2. Record values in Field Analytical Log Book.

* Calculation for aldehyde content in first bubbler.

** Calculation for aldehyde content in second bubbler.

Discussions--

Sampling at the prescribed rate of 0.5 l/min will result in a collection efficiency of approximately 85% in the first impinger. Using a backup impinger and analyzing each solution separately will result in an overall collection efficiency of greater than 97%.

Ammonia

Ammonia was collected in an impinger using 0.1 N H_2SO_4 as an absorbing solution. An aliquot was withdrawn and treated with hypochlorite and phenol. Indophenol, the reaction product

of ammonia, hypochlorite, and phenol, forms an intense blue color which is read at 603 nm. The color is linearly proportional to ammonia concentration. The method is applicable to a range of 0-25 $\mu\text{g NH}_3$.

Reagents--

Ammonium chloride, stock--Dissolve 3.141 g anhydrous NH_4Cl in a liter of ammonia-free water (1,000 mg/l NH_3).

Ammonium chloride, standard--Dilute 10.00 ml of stock solution to 2 l with ammonia-free water (5 mg/l NH_3).

EDTA, 5%--Dissolve 50 g EDTA, disodium salt, in 800 ml ammonia-free water. Add sufficient NaOH pellets to aid dissolution. Dilute to one liter.

Sodium hydroxide--50% solution.

Sodium hypochlorite--Dilute "Clorox" 1:1 with ammonia-free water. Available chlorine should approximate 2-3%.

Sodium nitroprusside, 0.05%--Dissolve 0.5 g sodium nitroprusside [$\text{Na}_2\text{Fe}(\text{CN})_5 \cdot 2\text{H}_2\text{O}$] in one liter of ammonia-free water.

Sodium phenolate--Dissolve 83 g phenol in 600 ml of ammonia-free water. Dissolve 32 g NaOH in 200 ml ammonia-free water. Carefully add the NaOH solution to the phenol solution with mixing and cooling. Dilute to one liter.

Procedure--

1. Transfer 10.0 ml of sample to 50-ml test tube.
2. Add two drops of 50% NaOH and mix.
3. Add 4 ml EDTA solution and mix.
4. Add 3 ml sodium phenolate solution and mix.

5. Add 3 ml 1:1 sodium hypochlorite solution and mix.
6. Add 4 ml 0.05% sodium nitroprusside solution and mix.
7. Place in a 37 °C water bath or oven for 15 min.
8. Cool and read at 630 μm in a 1-cm absorption cell.

Calibration--

1. Transfer 1.0, 2.0, 3.0, and 5.0, ml of the standard ammonia solution (5 mg/l) to each of four test tubes. Dilute to 10 ml with ammonia-free distilled water.
2. Continue with steps 3-8 as above.
3. Plot absorbance (ordinate) versus $\mu\text{g NH}_3$ (abscissa).

Note

1. Steps 4 through 7 should be performed without undue delay.
2. Zero optical density against distilled water.
3. Run reagent blank using 10.0 ml of ammonia-free water. Sodium phenolate darkens on standing. Prepare fresh whenever the optical density of the reagent blank becomes excessive.

Calculation--

$$\mu\text{g NH}_3/\text{m}^3 = \frac{V \cdot C \cdot 1,000}{F \cdot T}$$

where:

V = total volume of absorbing solution

C = $\mu\text{g NH}_3/\text{ml}$ found

F = sampling rate in liters/minute

T = sampling time in minutes

1000 = conversion of liters to m^3 .

Water-Soluble Sulfate

Particulates were collected on a 47-mm diameter fiber-glass filter, and the water soluble sulfate was dissolved in distilled water. Since metal cations which precipitate sulfate interfere, they are removed using a cation-exchange column; an aliquot is treated with Methyl Thymol Blue (MTB)-barium chloride solution. Barium reacts with the sulfate, liberating an equivalent amount of the free dye which is measured colorimetrically at 460 nm. The method is applicable to sulfate concentration from 0 to 20 mg/l ($200 \mu\text{g SO}_4$). Higher concentration can be determined by taking a smaller aliquot (<10 ml) and diluting to a final volume of 10 ml. Color response is not linear with sulfate concentration.

Reagents--

Barium chloride solution--Dissolve 2.50 g ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$) in distilled water and dilute to 500 ml in a volumetric flask.

Hydrochloric acid (1N)--Dilute 8.3 ml conc HCl to 100 ml.

Methyl thymol blue--Weigh out 0.050 g MTB into a 50-ml beaker. Add 5.0 ml of the BaCl_2 solution, 2.0 ml of 1N HCl, transfer to a 100-ml volumetric flask, and dilute to volume with 95% ethanol. Prepare fresh each day.

Sodium hydroxide (0.07N)--Dissolve 1.3125 g NaOH in distilled water and dilute to 500 ml.

Sulfate standard, 20 mg/l--Dilute 10.0 ml of a certified sulfate stock solution (1000 mg/l) to 500 ml in a volumetric flask.

Sample Preparation--

Place an aliquot of a Hi-Vol filter or the entire 47-mm glass fiber filter in a 59 ml (2 oz) glass bottle. Add 50 ml of water and seal the bottle using a polyseal cap. Place the sample in a sonic bath filled with cold water to a level equal to the sample level in the bottle. Operate the sonic bath for 30 min. Vacuum filter the extract in a plastic bottle and seal with a polyseal cap.

Procedure--

1. Slowly pass a 15-ml aliquot of the water soluble leachate through a small cation resin exchange column (IR-120 [H+]).
2. Transfer a 10.0 ml aliquot of the eluate to a 25-ml test tube.
3. Add 4.0 ml of the MTB solution and mix.
4. Add 2.0 ml of the NaOH solution and mix.
5. Transfer the solution to photocell of 10 mm light path.
6. Read absorbance against distilled H₂O at 460 nm within 5 min after NaOH addition and record.
7. Determine weight of sulfate, and calculate micrograms of SO₄/m³ of ambient air.

Calibration--

1. Transfer 10.0 ml of 0.0, 2.0, 4.0, 6.0, 10.0, 14.0, and 20.0 mg/l SO₄ standard to 25-ml test tubes.
2. Treat as in steps 3 through 6 above.
3. Plot absorbance (ordinate) versus micrograms (μg) of sulfate (abscissa).

Calculation--

$$\mu\text{g SO}_4/\text{m}^3 = \frac{V \cdot C \cdot 1000}{F \cdot T}$$

where:

V = total volume of dissolved particulate

C = $\mu\text{g/ml}$ of determined sulfate

F = sampling rate in liters/minute

T = sampling time in minutes

1000 = conversion of liters to m^3 .

Soluble Nitrates

Principle of Method--

Particulates were collected on a 47-mm diameter fiberglass filter. Water soluble nitrates were dissolved in hot distilled water. Nitrates react with brucine in strong fulfuric acid to develop a yellow color, measured at 410 nm. Absorbance is not linear with nitrate concentration. Standards must be run simultaneously with the samples. The method is applicable over the range of 5-250 μg for a 5-ml sample aliquot.

Reagents--

Brucine-sulfanilic acid--Dissolve 1.0 g of brucine sul-
and 0.1 g sulfanilic acid in 70 ml of water. Add
3 ml of concentrated HCl. Cool and dilute to 100 ml.
This solution is stable for several months.

Nitrate standard, 1000 mg/l--Dry potassium nitrate at
105 °C for 24 h. Dissolve 1.631 g in water, and
dilute to a liter. Alternately, a certified
1000-mg/l standard may be purchased. Prepare
working calibration standards of 1, 2, 5, 10,
20 mg/l. Using a microliuret, transfer 100, 200,
500, 1000, 2000 μl volumetric flask. Dilute to
volume.

Sulfuric acid--Carefully add 400 ml concentrated sulfuric acid to 60 ml of water. Cool and store in a tightly stoppered container.

Sample Preparation--

Place an aliquot of a Hi-Vol filter on the entire 47-mm fiberglass filter in a 59 ml (2-oz) glass bottle. Add 50 ml of water and seal the bottle using a polyseal cap. Place the sample in a sonic bath filled with cold water to a level equal to the sample level in the bottle. Operate the sonic bath for 30 min. Vacuum filter the extract in a plastic bottle and seal with a polyseal cap.

Procedure--

1. Transfer 5.0 ml of sample to a 50 ml beaker.
2. Transfer 5.0 ml of each of the nitrate working standard solutions to 50-ml beakers.
3. Add 1.0 ml of the brucine-sulfanilic acid solution to each of the beakers.
4. Prepare another 50 ml beaker containing 10.0 ml of the sulfuric acid solution, one for each sample and standard.
5. Transfer the contents of the beaker containing the sample to the beaker containing the sulfuric acid. Pour the mixture back and forth between the two beakers for a total of six transfers.
6. Store in the dark for 10 min for color development.
7. To each of the empty 50-ml beakers, add 10 ml water.
8. After the 10-min development time, transfer the water to the mixture and pur the mixture back and forth between the two beakers for a total of six transfers.
9. Allow the solution to cool in the dark for 20-30 min.

10. Prepare blank by mixing 15 ml of water and 10 ml of the sulfuric acid solution and allow to cool.
11. After cooling, read absorbance at 410 nm, zeroing the instrument with the blank using a 1.0-cm photo-cell.
12. Plot absorbance of the standards (ordinate) versus micrograms of nitrate added (abscissa), and draw a smooth curve through the data points.
13. Determine micrograms of nitrate in the samples from the calibration curve.
14. Compute concentration $\mu\text{g/ml}$ by dividing the mass of nitrate determined (Step 13) by the 5.0 ml sample aliquot.

Calculation--

$$\mu\text{gNO}_3/\text{m}^3 = \frac{V \cdot C \cdot 1000}{F \cdot T}$$

where:

V = total volume of dissolved particulate

C = $\mu\text{g/ml}$ of determined nitrate

F = sampling rate in liters/minute

T = sampling time in minutes

1000 = conversion of liters to m^3 .

Lead Analysis

One-half of the 47-mm glass fiber filter was placed in a 10-ml, standard-taper-stopper centrifuge tube along with 5 ml of constant-boiling acid. This acid was prepared by mixing one volume of 19% HCl with four volumes of 40% HNO_3 . The filter was leached at 105° C in the stoppered tube for one hour. The solution was then analyzed by atomic absorption spectrophotometry using a heated graphite furnace. Standard lead solutions were prepared in the same acid matrix.

Streaker Sampling

Five streaker samplers were employed on a continuous basis; two sampled ambient air, while three were monitoring the indoor locations. These units sample particulate material at the rate of 1 liter/min on Nuclepore filter media. The vacuum head traverses across the filter strip at the rate of 17.8 cm (7 in.) per week. These strips are removed and stored for future analysis employing proton-induced X-ray emission (PIXE) analysis techniques. Two-hour average concentrations can be determined simultaneously for elements of atomic nos. 16 through 35 [plus 82 (lead)] with this method.

Periodically, specific sampling periods (8-24 h) were selected for analyses. These periods coincided with specific indoor activities which were concurrently monitored by the continuous equipment. The analyses were performed by the Florida State University.

SECTION 4

DATA MANAGEMENT SYSTEM

The computer system that supported the Indoor-Outdoor Air Pollution Project consisted of 13 programs, 4 permanent disk files, and 5 major input forms. These are specified in detail in the following sections.

PROGRAMS AND FILES

Figure 57 illustrates the programs and file interactions.

Files

File 1 (1Ø001)* --

This file was used for the continuous data storage. Each 96 word record stored one hour of continuous data.

File 2 (1Ø002) --

File two was the storage location for the physical data (temperature, relative humidity, wind speed, wind direction). This 96 word record stored 1-d block of data per sampling point.

File 3 (1Ø003) --

The 24-h sampling data was stored in File 3. A maximum of 14 parameters for 4 sampling points could be stored in each 64 word record.

* Ø = letter O

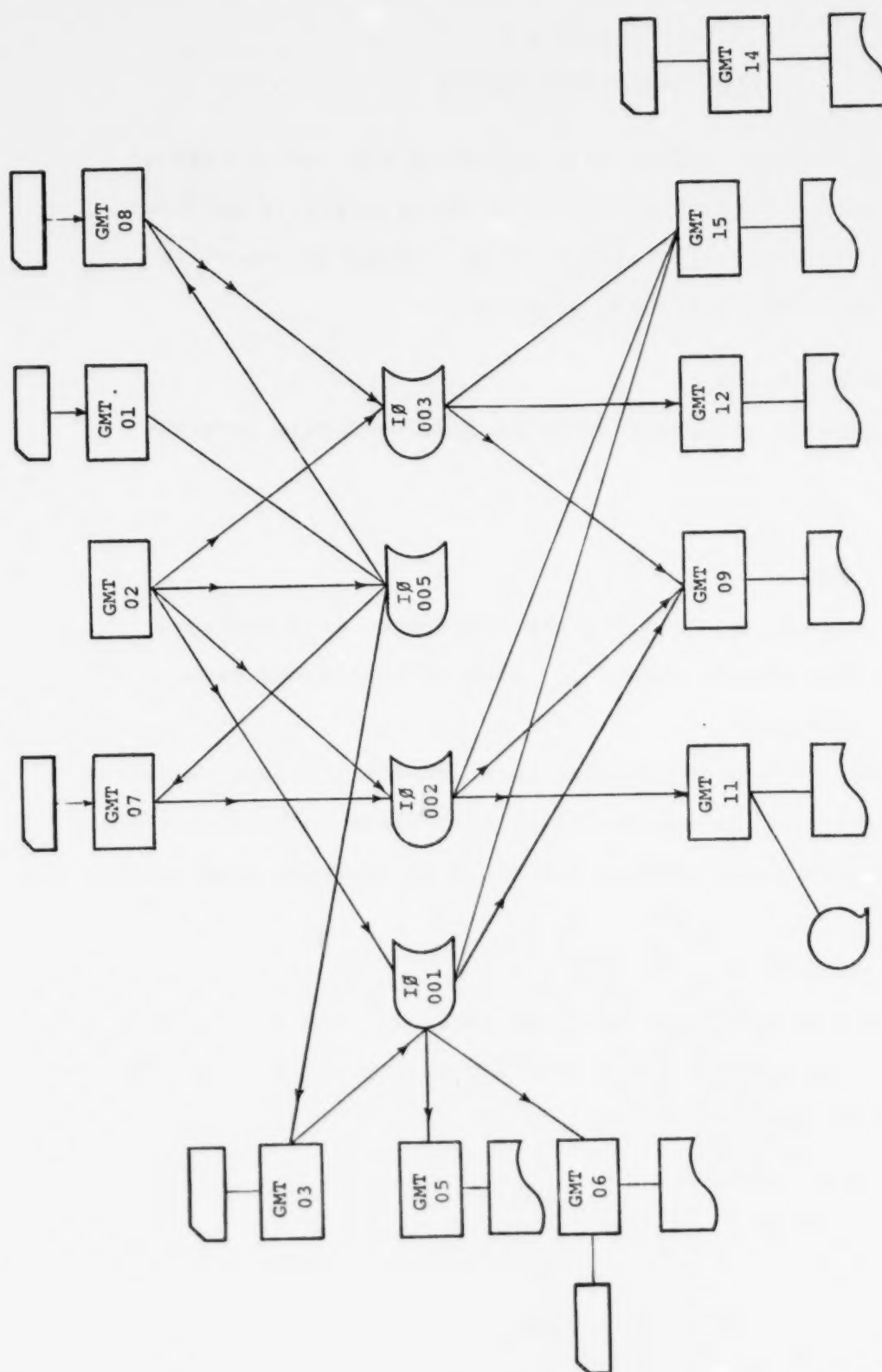


Figure 57. System diagram.

File 5 (I0005)--

File 5 was used for miscellaneous data storage with records 1 and 2 being reserved for sampling dates. Record 1, Integer format; Record 2, Floating point format; Records 3-80, open.

Forms

3252-1 Pollutant Analysis Input (Figure 58)--

This form was used for transcribing strip chart data to a usable data analysis format.

Site	Columns 1 - 10 Code for site identification
Date	Columns 11-16 Month, Day, Year, MMDDYY 071576
Time	Columns 17-20 Hour, Minute, HHMM 0120
CO	Columns 22-23 Percent of chart
SO _{2e}	Columns 24-25 Percent of chart
NO	Columns 26-27 Percent of chart
NO _x	Columns 28-29 Percent of Chart
O ₃	Columns 30-31 Percent of chart
CH ₄	Columns 32-33 Percent of chart
THC	Columns 34-35 Percent of chart

POLLUTANT ANALYSIS INPUT

LOCATION

1	2	3	4	5	6	7	8	9	10

DATE

11	12	13	14	15	16



TIME				LOC	CO	SO ₂	NO	NO _x	O ₃	CH ₄	THC	CO ₂								
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
				1																
				2																
				3																
				4																
				1																
				2																
				3																
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				4																
				1																
				2																
				3																
				4																

Figure 58. Pollutant analysis input form.

CO₂ Columns 36-37
 Percent of chart

-8 was used to indicate equipment in calibration.

-9 was used to indicate equipment breakdown.

3252-2 Hourly Data Form (Figure 59)--

The main purpose of the Hourly Data Form was for the physical data transcription.

Site Columns 1-10
 Code for site identification

Year Columns 15-16
 YY Example 76

Month Columns 17-18
 MM Example 08

Year Columns 19-20
 DD Example 09

ST HR Columns 21-22
 Start Hour
 00 AM
 01 PM

Parameter Code - Column 27

'1' Temperature
2 Relative humidity
3 Wind speed
4 Wind direction

Loc - Columns 31
 Location of reading
 numeric 1, 2, 3, or 4

RDG 1 - RDG 12
 Integer values and right justified

Temperature to nearest degree
Relative humidity to nearest percent
Wind speed to nearest mph
Wind direction to nearest degree

IF ST HR equal 0
Hours 0-11

IF ST HR equal 1
Hours 12-23

3252-3 24-Hour Sampling Interval (Figure 60)--

Site Columns 1-10
Site identification

Parameter Code Columns 11-13
005 Total suspended particulates
006 Sulfates
007 Nitrates
008 Aldehydes
009 Lead
010 Acetone
011 Benzene
012 Carbon tetrachloride
013 Chloroform
014 P-Dioxane
015 Ethyl acetate
016 Ethylene dichloride
017 Methyl ethyl ketone
018 Styrene
019 Tetrachloroethylene
020 Toluene
021 1,1,1 Trichloroethane
022 1,1,2 Trichloroethane
023 1,1,2 Trichloroethene
024 Trichlorotrifluoroethane
025 Xylene
026 Respirable suspended particulates

Month Columns 14-15

Year Columns 16-17

Day Columns 21-22
Start time

Location 1 Column 33-36
Location 2 Column 37-40
Location 3 Column 41-44
Location 4 Column 45-48



24-HOUR SAMPLING INTERVAL

SITE _____

CITY _____

ADDRESS _____

SITE									
1	2	3	4	5	6	7	8	9	10

11	12	13

PARAMETER
CODE

14	15

MONTH

16	17

YEAR

DAY ST HR			LOCATION 1				LOCATION 2				LOCATION 3				LOCATION 4				
19	20	21	22	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
0.1																			
0.2																			
0.3																			
0.4																			
0.5																			
0.6																			
0.7																			
0.8																			
0.9																			
1.0																			
1.1																			
1.2																			
1.3																			
1.4																			
1.5																			
1.6																			
1.7																			
1.8																			
1.9																			
2.0																			
2.1																			
2.2																			
2.3																			
2.4																			
2.5																			
2.6																			
2.7																			
2.8																			
2.9																			
3.0																			
3.1																			

DF → 4 3 2 1 0 4 3 2 1 0 4 3 2 1 0 4 3 2 1 0

Figure 60. 24-hour sampling interval form.

3252-4

Calibration Data (Figure 61)--

This data form was used to record data for a linear regression analysis of instrument calibration data. The form is divided into three parts.

- 1 Original calibration input
- 2 Daily zero and span
- 3 Final calibration input

Card 1

Equipment	Columns 1-2 Equipment Co.
Date	Columns 3-8 MMDDYY (071476)

Concentration	Columns 9-13 17-21 25-29 33-37 41-45 49-53 57-61
---------------	--

Concentration of the standard

- Decimal place assumed at the very end of field (F5.0)
- If decimal values are needed, use one field for the decimal (71.73) (.0153)

Chart displacement columns	14-16 22-24 30-32 38-40 46-56 62-64
----------------------------	--

Percent of chart to the nearest tenth of a percent

305	=	30.5
010	=	01.0

Column 80 = '1'

[illegible]

3232-5 (6-76)

Card 2

Equipment	Columns 1-2 Equipment Number
Date	Columns 3-8 MMDDYY (071476)
Zero Read	Columns 9-11 Percent of chart to the nearest tenth of a percent 351 = 35.1
Zero adjusted	Columns 12-14 Percent of chart to the nearest tenth of a percent
Concentration	Columns 15-19 Concentration of standard
-	Decimal place assumed at the very end of field (F5.0)
-	If decimal values are needed, use one field for the decimal (71.73) (.0153)
Chart displacement columns 20-22	
Percent of chart to the nearest tenth of a percent 351 = 35.1	
Column 80 = '2'	

Card 3

Same as Card 1 except Column 80 = '3'.

3252-6 Miscellaneous Input (Figure 62)--

The 3252-6 form was used for the remaining data that was without data forms. All data fields should have followed SAROAD coding format.

SITE _____

CITY _____

ADDRESS _____

Site

2 3 4 5 6 7 8 9 10

Time

14

Year

15 16

Month

17 18

Name PARAMETER Code		Name PARAMETER Code		Name PARAMETER Code		Name PARAMETER Code				
23 24 25 26 27		37 38 39 40 41		51 52 53 54 55		65 66 67 68 69				
Method	Units	DP	Method	Units	DP	Method	Units	DP		
28 29 30 31 32			42 43 44 45 46			56 57 58 59 60			70 71 72 73 74	
Day	St Hr	Day		St Hr	Day		St Hr	Day		St Hr
13 14 15 16 17	21 22 23 24 25	33 34 35 36 37	47 48 49 50 51	61 62 63 64 65	75 76 77 78 79	83 84 85 86 87	93 94 95 96 97			
18 19 20 21 22										

Figure 62. Miscellaneous data form.

Site	Columns 1-10 Site identification
Time	See SAROAD codes
Year	Columns 15-16 (76)
Month	Columns 17-18 (08)
Day	Columns 19-20 (09)
ST HR	Columns 21-22 Start Hour (02) (15)
Parameter Code	See SAROAD Code
Method	See SAROAD Code
Units	See SAROAD Code
DP	Decimal Point (0-4)

Programs

GMT01

This program read in the dates for use by the GEOMET System and puts these dates in File 5, records 1 and 2.

GMT02

This program initialized Files 1-2, all records and all fields to -1's.

GMT03

Program GMT03 used the data form 3252-1 plus linear regression analysis values and File 5 dates to enter the continuous data onto File I0001.

GMT05

This program produced a report that indicated the missing data in File 1.

GMT06

This program produced a final report of the Continuous Data stored in File 1 with hourly averages and daily averages by pollutant by probe.

GMT07

This program loaded the data from form 3252-2 into File 2 using File 5 dates for validation.

GMT08

This program loaded File 3 with data from form 3252-3 using File 5 dates for validation.

GMT09

This program created the formatted tape for GEOMET.

GMT10

This program was a utility program for listing File 1-3 for validation checking.

GMT11

This program produced a final report of the Physical Data from File 2.

GMT12

This program produced the final report of the Miscellaneous Data from File 3.

GMT14

This program provided the statistical analysis for the GEOMET System plus it produces the Calibration Analysis Report.

GMT15

Equipment efficiency report.

Final Reports

Pollutant Summary Report	Figure 63
Physical Data Report	Figure 64
Miscellaneous Data Report	Figure 65
Calibration Analysis Report	Figure 66
Home Owners Activity Log	Figure 67
Energy Consumption Data Report	Figure 68

POLLUTANT SUMMARY ANALYSIS

PEDCO ENVIRONMENTAL
SPECIALISTS COURTYARD TES

T

DATE 5-15-76

TIME	LOCATION	CO	SO(2)	NO	NO(2)	CO(3)	CH(4)	THC-CH(4)	CO(2)
0-00	1	7	1	11	0	2	15	30	150
0-05	2	5	1	5	0	1	10	20	100
0-10	3	22	4	47	0	6	45	90	450
0-15	4	47	9	106	0	14	94	138	940
0-20	1	12	2	23	0	3	25	50	250
0-25	2	12	2	23	0	3	25	50	250
0-30	3	12	2	23	0	3	25	50	250
0-35	4	12	2	23	0	3	25	50	250
0-40	1	17	3	35	0	5	35	70	350
0-45	2	17	3	35	0	5	35	70	350
0-50	3	17	3	35	0	5	35	70	350
0-55	4	17	3	35	0	5	35	70	350

HOUR AVERAGE

1	12	2	23	0	3	25	50	250
2	11	2	21	0	3	23	46	233
3	17	3	35	0	4	35	70	350
4	25	4	54	0	7	51	102	513

1-00	1	7	1	11	0	2	15	30	150
1-05	2	7	1	11	0	2	15	30	150
1-10	3	7	1	11	0	2	15	30	150
1-15	4	7	1	11	0	2	15	30	150
1-20	1	-1	-1	-1	-1	-1	-1	-1	-1
1-25	2	-1	-1	-1	-1	-1	-1	-1	-1
1-30	3	-1	-1	-1	-1	-1	-1	-1	-1
1-35	4	-1	-1	-1	-1	-1	-1	-1	-1
1-40	1	7	1	11	0	2	15	30	150
1-45	2	7	1	11	0	2	15	30	150
1-50	3	7	1	11	0	2	15	30	150
1-55	4	7	1	11	0	2	15	30	150

HOUR AVERAGE

1	7	1	11	0	2	15	30	150
2	7	1	11	0	2	15	30	150
3	7	1	11	0	2	15	30	150
4	7	1	11	0	2	15	30	150

NOTES (-1) - NO DATA WAS REPORTED.
(-9) - EQUIPMENT IN CALIBRATION.

Figure 63. Pollutant summary report.

POLLUTANT SUMMARY ANALYSIS

PEDCO ENVIRONMENTAL
SPECIALISTS COURTYARD TES
T

DATE 5-24-76

DAY AVERAGE
LOCATION

	CO	SO(2)	NO	NO(2)	O(3)	CH(4)	THC-CH(4)	CO(2)
1	18	3	38	0	5	37	75	375
2	10	3	38	0	5	37	75	375
3	18	3	38	0	5	37	75	375
4	16	3	38	0	5	37	75	375

Figure 63. (cont'd)

PHYSICAL DATA REPORT

PEDCO ENVIRONMENTAL
SPECIALISTS COURTYARD YES

DATE 5-15-76

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

LOCATION 1

TEMPERATURE (F) 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

LOCATION 2

TEMPERATURE (F) 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

LOCATION 3

TEMPERATURE (F) 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
WIND SPEED (MPH) 15 15 15 15 15 15 15 15 15 15 30 30 30 30 30 30 30 30 30 30 30 30
WIND DIRECTION 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300 315 330 345 360

LOCATION 4

TEMPERATURE (F) 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

DATE 5-16-76

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23

LOCATION 1

TEMPERATURE (F) -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

LOCATION 2

TEMPERATURE (F) -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

LOCATION 3

TEMPERATURE (F) -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
WIND SPEED (MPH) 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25 25
WIND DIRECTION -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

LOCATION 4

TEMPERATURE (F) -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1
REL HUMIDITY -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1 -1

Figure 64. Physical data report.

MISCELLANEOUS DATA REPORT

PEUCO ENVIRONMENTAL
SPECIALISTS COURTYARD YES

LOC ***** POLLUTANT *****

DATE 5/15/76

1	2	3	100	5	6	100	8	9	10	11	12	13	14	15
2	16	17	100	19	20	100	22	23	24	25	26	27	28	29
3	30	31	100	33	34	100	36	37	38	39	40	41	42	43
4	44	45	100	47	48	100	50	51	52	53	54	55	56	57

DATE 5/16/76

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
4	44	45	46	47	48	49	50	51	52	53	54	55	56	57

DATE 5/19/76

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
4	44	45	46	47	48	49	50	51	52	53	54	55	56	57

DATE 5/22/76

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
4	44	45	46	47	48	49	50	51	52	53	54	55	56	57

DATE 5/24/76

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
4	44	45	46	47	48	49	50	51	52	53	54	55	56	57

DATE 5/25/76

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	16	17	18	19	20	21	22	23	24	25	26	27	28	29
3	30	31	32	33	34	35	36	37	38	39	40	41	42	43
4	44	45	46	47	48	49	50	51	52	53	54	55	56	57

Figure 65. Miscellaneous data report.

CALIBRATION DATA ANALYSIS REPORT

EQUIPMENT NO. 01

DATE 7/ 1/76

CONCENTRATION UNITS ()	CHART DISPLACEMENT	CALCULATED CONCENTRATION	DELTA
0.0000	0.0000	-0.0386	0.0386
4.0000	20.0000	3.9813	0.0186
7.8000	39.0000	7.8003	-0.0003
11.6000	59.0000	11.8204	-0.2204
15.2000	75.0000	15.0364	0.1635

SLOPE = 4.9750

INTERCEPT = 0.1924

SIGMA = 0.0976

** SAMPLE 4IS & 2 SIGMA, THEREFORE IT IS BEING DROPPED FROM THE CALCULATIONS.

SLOPE = 4.9750

INTERCEPT = 0.1924

SIGMA = 0.1347

** DAILY DATA ANALYSIS

DATE	ZERO	ZERO ADJ	CONCENTRATION	CONCENTRATION CALCULATED	DELTA	CHART DISPLACEMENT
7 3 76	6.0	5.0	2.3000	1.9713	0.3286	15.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 4 76	3.1	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 5 76	4.0	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 6 76	5.0	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 7 76	6.0	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 8 76	4.0	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 9 76	17.0	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 10 76	3.0	5.0	2.3000	1.7301	0.5698	13.8
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 11 76	3.1	5.0	2.3000	1.7703	0.5296	14.0
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 12 76	5.0	5.0	2.3000	1.6698	0.6301	13.5
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						

Figure 66. Calibration data analysis report.

7 13 76	4.6	5.0	2.3000	1.7301	0.5698	13.8
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 14 76	6.0	5.0	2.3000	1.6698	0.6301	13.5
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 15 76	7.0	5.0	2.3000	1.6698	0.6301	13.5
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 16 76	7.0	5.0	2.3000	1.6698	0.6301	13.5
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 17 76	6.0	5.0	2.3000	1.6095	0.6904	13.2
** THE DELTA VALUE IS GREATER THAN 2-SIGMA						
7 18 76	4.0	5.0	2.3000	1.6095	0.6904	13.2
** THE DELTA VALUF IS GREATER THAN 2-SIGMA						
** FINAL STANDARDS						
DATE 7 18 76						
CONCENTRATION	CHART	CALCULATED	DELTA			
UNITS ()	DISPLACEMENT	CONCENTRATION				
0.0000	0.0000	0.2296	-0.2296			
4.0000	20.0000	4.2642	-0.2642			
7.8000	36.0000	7.8953	-0.0953			
11.6000	56.0000	11.5264	0.0735			
15.2000	70.0000	14.3506	0.8493			
SLOPE = 4.9571						
INTERCEPT = -1.1383						
SIGMA = 0.3166						
** SAMPLE 5 IS > 2 SIGMA, THEREFORE IT IS BEING DROPPED FROM THE CALCULATIONS.						
SLOPE = 4.9571						
INTERCEPT = -1.1383						
SIGMA = 0.3778						
THE SIGMA VALUE FOR THE SECOND SET OF STANDARDS 0.3778						
HAS MORE THAN A 10% DEVIATION FROM THE FIRST SET OF STANDARDS 0.1347						

Figure 66. (cont'd)

ACTIVITY RECORD

Residence of _____

Address _____

Sampling Period Start Date _____

End Date _____

Please list all cleaning materials, aerosols, cigarettes, air fresheners, deoderants or other such materials that you use in your house. Give the brand name and what it is used for. Example, Dawn - dish washing detergent. When refering to these materials in the daily activities record you need only list the code letter.

Code Letter	Description
A	_____
B	_____
C	_____
D	_____
E	_____
F	_____
G	_____
H	_____
I	_____
J	_____
K	_____
L	_____

Figure 67. Home owner's activity log.

DAILY ACTIVITY RECORD

Daily activity record of the _____ residence
for the day of _____

1. Did you cook breakfast? Yes () No ()
What did you cook? _____
What time did you start? _____ How long did you cook? _____
2. Did you cook lunch? Yes () No ()
What did you cook? _____
What time did you start? _____ How long did you cook? _____
3. Did you cook dinner? Yes () No ()
What did you cook? _____
What time did you start? _____ How long did you cook? _____
4. Did you cook or bake any thing other than regular
meals? Yes () No ()
What did you cook or bake? _____
What time did you start? _____ How long did you cook? _____
5. Did you turn on the range hood fan while cooking?
Yes () No ()
What time did you turn it on? _____ off _____
6. Did you wash dishes today? Yes () No ()
At what times? _____ For how long? _____
7. Did you have guest today? Yes () No ()
How many guest did you have? _____
What time did they arrive? _____ Leave _____

Figure 67. (cont'd)

8. Was there any period of time that nobody was home?
Yes () No ()
What time? From _____ To _____
9. Did you, your family or your guest smoke? Yes () No ()
What was smoked? cigarettes () cigar () pipe ()
How many or how often? _____ What times _____
In what rooms? _____
10. Did you do any cleaning today? Yes () No ()
What rooms did you clean? _____
What time did you start? _____ Stop _____
Was cleaning continuous? () Intermittent ()
List cleaning materials used? _____
11. Did you vacuum clean today? Yes () No ()
At what time did you start? _____ Stop _____
Was vacuuming continuous? () Intermittent ()
What rooms did you clean? _____
12. Did you do the laundry today? Yes () No ()
What time did you start? _____ Stop _____
How many loads did you do? _____
13. Did you use the clothes dryer? Yes () No ()
What time did you start? _____ Stop _____
Did the dryer run continuous? Yes () No ()
14. Did you use any air freshener today? Yes () No ()
At what time? _____ What brand did you use? _____
In what room did you use it? _____

Figure 67. (cont'd)

15. Did you use any aerosols today? Yes () No ()
At what time? _____ What brand did you use? _____
In what room did you use it? _____
16. Did you open any windows today? Yes () No ()
At what time were they opened? _____ Closed? _____
In what rooms were they opened? _____
17. Did you use a fireplace? Yes () No ()
What time did you use it? Start _____ Stop _____
18. Please list any additional activities that may have taken place in the house that have not been listed. This would include activities related to hobbies, repairs, painting etc. A short description of the activity, any materials used if any, room in which the activity had taken place, and time of starting and ending should be included. If there are any questions on what should be included please ask the PEDCo personnel for assistance.
- _____

- Activity record completed by _____ Date _____
Activity record checked by _____ Date _____

Figure 67. (cont'd)

ENERGY CONSUMPTION DATA

City Name	Year	Month	Day	Hour	Minute	Second	Time	Zone	Latitude	Longitude	Altitude	Population	Area	Country	State	County	City	Street	Box	Zip	Phone	Fax	Telex	Internet	E-mail	Web	Other	Notes
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS	ADAMS	ADAMS	ADAMS	99501	907							
Alaska	1999	01	01	00	00	00	00:00:00	UTC	66.0000	-150.0000	1500	60000	150000	USA	AK	ADAMS												

[illegible]

Figure 68. Energy consumption data sheet.



TAPE OUTPUT FORMAT

The transmission tape to GEOMET was:

9 track

800 bpi

EBCDIC Code

No label

Record size 110 characters

Block size 10 records/block

Each record will follow a basic format of:

Columns 1-2 Record code

Columns 3-22 Site code

Columns 23-110 Data

Record codes:

1	Comments
2	Continuous Data
3	Physical Data
4	24-h Data
6	Miscellaneous Data
98	End of Data Type
99	End of Data

Record Code 1 Data

Columns 24-100 Study Comments

Record Code 2 Data

<u>Field</u>	<u>Columns</u>	<u>Format</u>	<u>Comment</u>
Date	24-29	I6	MMDDYY
Time	30-33	I4	HHMM
Location	34	I1	
CO	35-40	I6	
SO ₂	41-46	I6	
NO	47-52	I6	
NO ₂	53-58	I6	
O ₃	59-64	I6	
CH ₄	65-70	I6	
THC	71-76	I6	
CO ₂	77-82	I6	
	83-110	Blank	

Record Code 3 Data

<u>Field</u>	<u>Columns</u>	<u>Format</u>	<u>Comment</u>
Date	23-29	I6	MMDDYY
Location	29		
Parameter	30-31		
Midnight	32-34		
1	35-37		
2	38-40		
3	41-43		
4	44-46		
5	47-49		
6	50-52		
7	53-55		
8	56-58		
9	59-61		
10	62-64		
11	65-67		
12	68-70		
13	71-73		
14	74-76		
15	77-79		
16	80-82		
17	83-85		
18	86-88		
19	89-91		
20	92-94		
21	95-97		
22	98-100		
23	101-103		

Parameter	01	Temperature
	02	Relative Humidity
	03	Wind Speed
	04	Wind Direction

Record Code 4 Data

<u>Field</u>	<u>Columns</u>	<u>Format</u>	<u>Comment</u>
Date	23-28	I6	MMDDYY
Parameter Code	29-30	I2	
START HR	31-32	I2	
Location 1	33-36	I4	
2	37-40	I4	
3	41-44	I4	
4	45-48	I4	
	49	I4	Decimal places to the left
Date	50-55	I6	
Parameter Code	56-57	I2	
START HR	58-59	I2	
Location 1	60-63	I4	
2	64-67	I4	
3	68-71	I4	
4	72-75	I4	
	76	I1	
	77-110	Blank	

Record Code 6 Data

<u>Field</u>	<u>Columns</u>	<u>Format</u>	<u>Comment</u>
Time interval	23	I1	
Date	24-29	I6	YYMMDD
ST HR	30-31	I2	Start Time
Parameter Code*	32-36	I5	
Location	37-38	I2	
Units 1	39-40	I2	
Decimal			
Point 1	41	I1	Decimal point
Data Value 1	42-45	I4	
Parameter			
Code 2	46-50	I5	
		I5	

* Parameter code the same as for 24-h sampling codes.

<u>Field</u>	<u>Columns</u>	<u>Format</u>	<u>Comment</u>
Location 2	51-52	I2	
Units 2	53-54	I2	
Decimal Point 1	55	I1	
Data Value 2	56-59	I4	
Parameter Code 3	60-64	I5	
Location 3	65-66	I2	
Units 3	67-68	I2	
Decimal Point 3	69	I1	
Data Value 3	70-73	I4	
Parameter Code 4	74-78	I5	
Location 4	79-80	I2	
Units 4	81-82	I2	
Decimal Point 4	83	I1	
Data Value 4	84-87	I4	

Two backup copies of this tape will be maintained by PEDCo Environmental, Inc. One tape will remain on-site at the computer center and one placed in a local bank vault for backup security.

DATA HANDLING

The indoor-outdoor air pollution project required a considerable amount of data handling. Figure 69 breaks the data handling flow down to eight major functions and shows area of responsibility of these functions.

Due to departmental interaction and reporting deadlines, a schedule for data handling (Figure 70) is used to keep tabs on data handling progress. The 6-week schedule illustrates the duration of function, starting with the remote lab startup and ending with mailing of the data tape to the client.

Field Staff

Field Staff
Office Staff
Lab Staff

Data Clerk

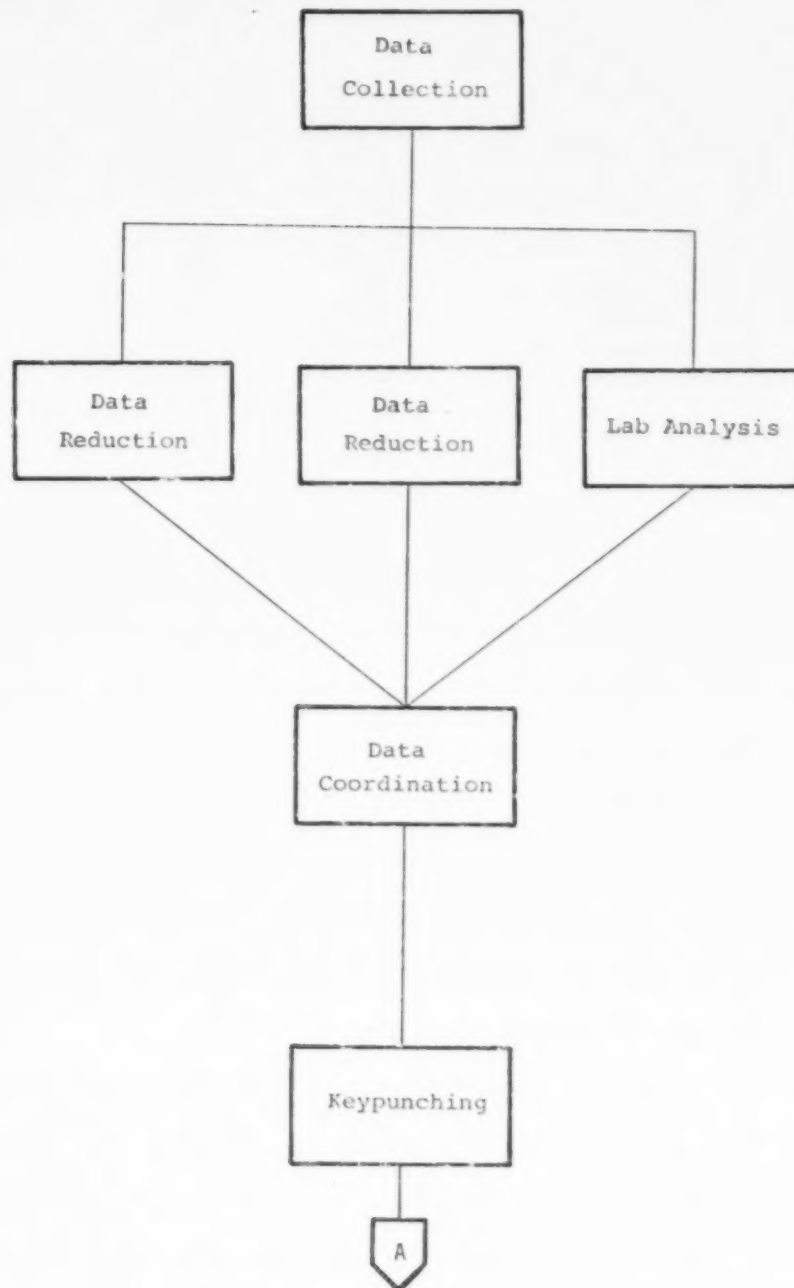


Figure 69. Data flow of indoor-outdoor air project.

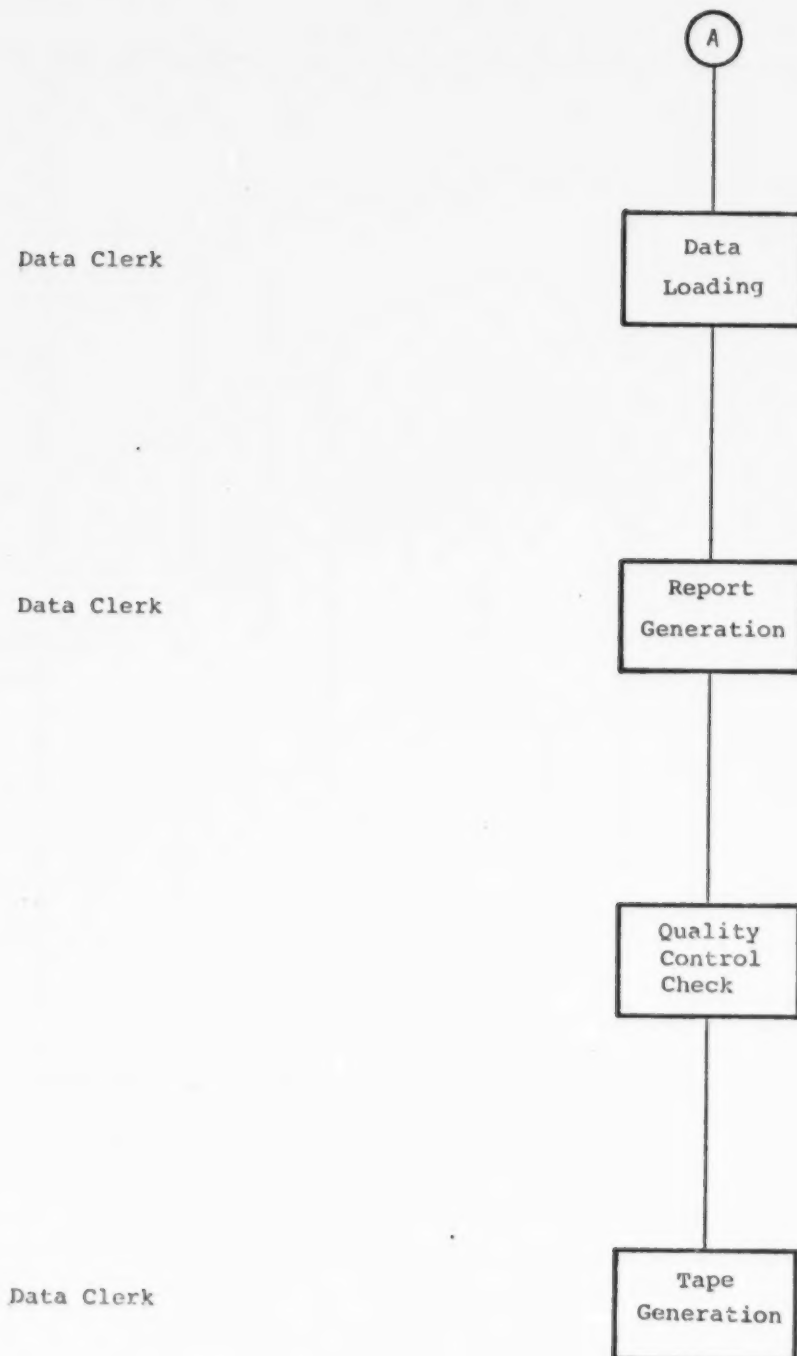


Figure 69. (cont'd)

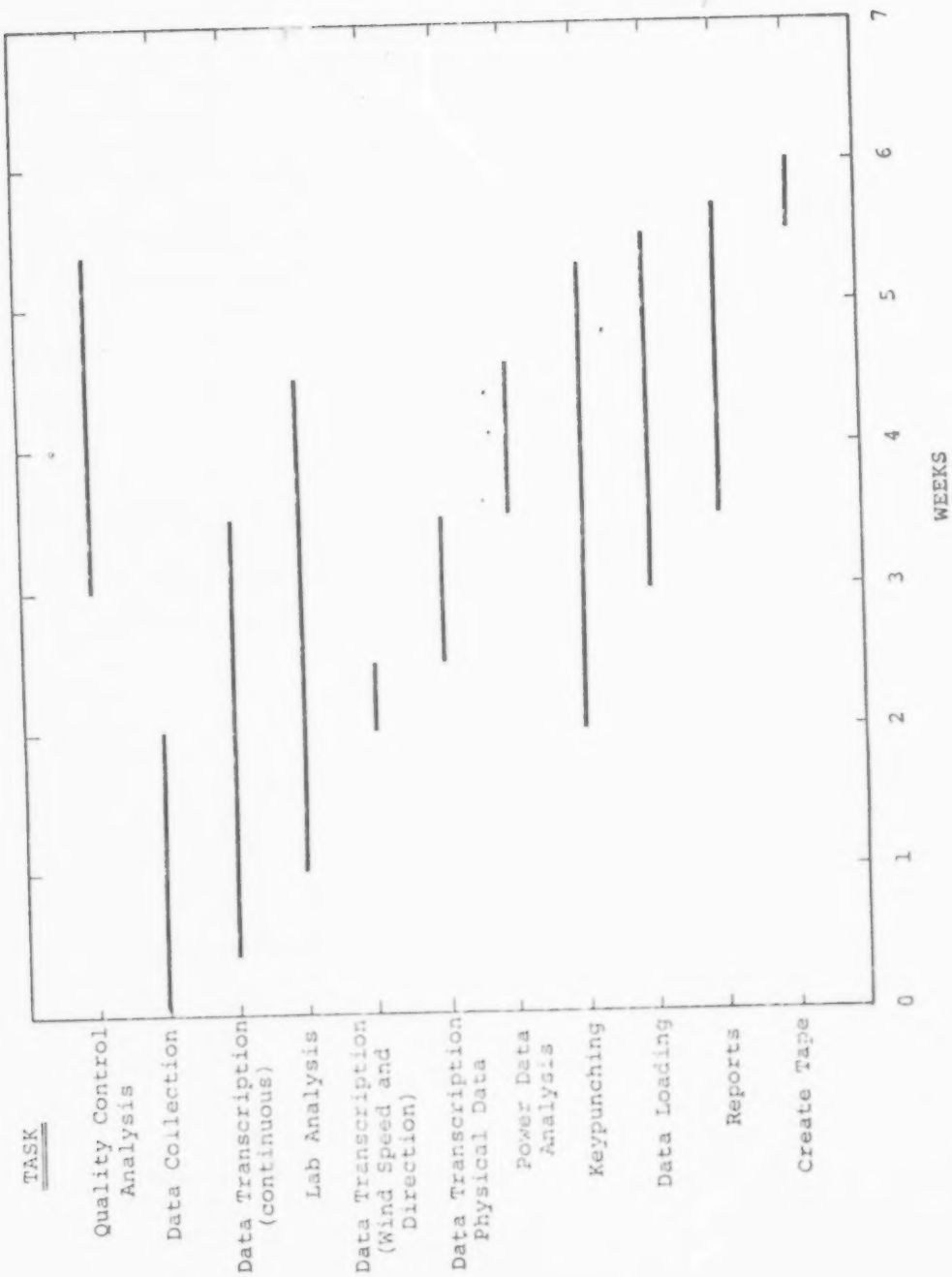


Figure 70. Schedule for data handling.

SECTION 5

QUALITY ASSURANCE PROGRAM: TOTAL CONCEPT

FIELD PROGRAM QUALITY CONTROL

Introduction

Regardless of the magnitude of scope of any air monitoring program, it is imperative that actual sampling be performed within specified guidelines to insure the quality and accuracy of the data. It is with these objectives in mind that this section has been developed.

Specifically, this section is addressed to the field sampling quality assurance program with respect to the following parameters:

- ° NO/NO_x
- ° CO₂
- ° CO
- ° O₃
- ° SO₂
- ° THC/CH₄
- ° Wind speed/wind direction
- ° Temperature/relative humidity
- ° Total suspended particulates
- ° Organic vapors
- ° Aliphatic aldehydes.

Eight continuous gas analyzers were used in conjunction with a programmable solenoid switching mechanism to collect 5-min samples at each of four locations. One complete sampling cycle required 20 min, resulting in

three 4-min samples per hour from each location. For a detailed explanation of the sampling methodology, refer to Section 3 of this document.

Wind speed and direction measurements were continuously made at a height of 9.1 m (30 ft) and remotely recorded in the trailer. A hygrothermograph was placed in the vicinity of the sampling probe to constantly measure and record temperature and relative humidity at each location. Total suspended particulates were collected daily on 47 mm glass fiber filters at a sampling rate of 84-112 l/min (3-4 ft³/min) for a period of 24 h. Organic vapors were collected daily on charcoal adsorption tubes for a period of 24 h at a flow rate of 200 cm³/min. Flow rates were regulated with calibrated hypodermic needles. Aliphatic aldehydes were collected in two impingers, operated in series, each containing 25 ml of absorbing reagent. A sampling train for each location was set up in the trailer. Flow rates of 500 cm³/min were obtained by the use of calibrated hypodermic needles. Table 7 lists pertinent operating characteristics of this instrumentation.

Specific Quality Control Techniques

NO/NO_x --

A Meloy Model NA-520-2 chemiluminizer was used to continuously monitor and record NO/NO_x levels. The analyzer operated on the principle of chemiluminescence and was operated at a 0 to 0.5 ppm measuring range.

TABLE 7. OPERATING CHARACTERISTICS AND CALIBRATION
PRINCIPLES OF CONTINUOUS MONITORS

Pollutant	Principle of detection	Manufacturer model	Concentration (ppm)		Calibration principle
			Range(s)	Limit of detection	
NO	Chemiluminescent	Meloy-NA-502-2	0-0.5 0-1.0 0-2.0 0-5.0	0.005	Gas phase titration
NO _x	Chemiluminescent	Meloy-NA-520-2	0-0.5 0-1.0 0-2.0 0-5.0	0.005	Gas phase titration
CO ₂	Nondispersive infrared	Beckman-865	0-2,500 0-50,000	25 500	Standard gas dilution
CO	Nondispersive infrared with flowing ref. cell	Beckman-865	0-50	0.50	Standard gas
O ₃	Chemiluminescent	Meloy-OA-350-2	0-0.5	0.005	Gas phase titration
SO ₂	Flame photometric	Meloy-SA-185-2A	0-0.5	0-0.5	Permeation tube
CH ₄	Flame ionization with selective TCH oxidizer	MSA-11-2	0-5 0-20	0-0.5	Standard gas dilution
THC	Flame ionization with selective THC oxidizer	MSA-11-2	0-5 0-20	0.05 0.20	Standard gas dilution
Wind/speed direction	Direction-syncho; speed-d/c/ magneto	Bendix Aerovane 141/120	0-100 mph 0-540°	0.5 mph 5°	Magnetic compass and bearing wear
Temperature relative humidity	Temp.-bi-metallic strip RH human hair	Weather Measure W-311	Adjustable 0-100°	1°F 1% RH	ASTM mercury thermometer and sling psychrometer

At the beginning of each 2-week sampling session, the analyzer was dynamically calibrated. This calibration technique was based upon the rapid gas phase reaction between NO and O_3 to produce NO_2 . The quantitative nature of the reaction was used in a manner such that, once the concentration of reacted NO is known, the concentration of NO_2 is determined. Ozone was added to excess NO in a dynamic calibration system, and a chemiluminescence NO analyzer was used to measure changes in NO concentration. Upon the addition of O_3 , the decrease in NO concentration observed on the calibrated NO analyzer was equivalent to the concentration of NO_2 produced. The amount of NO_2 generated was varied by changing the concentration of O_3 added.

During each day of the sampling session, the analyzer was zeroed and spanned to detect any change in calibration. A source of chemically zero air was sent to the inlet of the analyzer for a period of approximately 5 min. If the value obtained from the analyzer differed by more than $\pm 1.08\%$ of full scale from the zero point established by the previous reference calibration, the unit was declared "inoperable," and remedial maintenance was immediately undertaken. Once the unit had been repaired, a new reference calibration curve was generated, and the unit was declared "operable." To conduct the span check, the certified NO span gas was sent to a dilution system where it mixed with a source of zero air. The flow rate of each gas was kept constant so that the same concentration of NO would be obtained each day. The NO/NO_x analyzer

sampled this gas stream of diluted NO for 5 min. If the value obtained at the recorder was greater than $\pm 2.0\%$ of full scale from the span point established by the previous reference calibration, the unit was declared "inoperable." Remedial maintenance procedures were activated, and, when completed, the unit was recalibrated and declared "operable."

At the end of the sampling program, the analyzer was dynamically calibrated with Meloy CNOS40 calibrator.

Carbon Dioxide--

The CO₂ analyzer employed in this study was a Beckman Model 865 infrared analyzer. The operation of this monitor is based on a differential measurement of the absorption of infrared energy. The measuring range of the analyzer was set at 0 to 2500 ppm.

Prior to the start of actual sampling, the CO₂ analyzer was dynamically calibrated by using a certified tank (aluminum) of compressed CO₂ traceable to NBS primary standards and a source of zero air. The streams of CO₂ and zero air were mixed in a glass chamber to the desired concentration, then injected into the sampling manifold where the analyzer took its sample. A five-point calibration curve was then produced and recorded.

On a daily basis, a one-point zero and span check was conducted. The analyzer was challenged with a concentration of CO₂ or zero air. If the zero level had drifted by more than $\pm 1.0\%$ of full scale, or if the span had changed by more

than $\pm 2.0\%$ of full scale from their respective reference calibration points, the analyzer was removed from the system, repaired, recalibrated, and placed back on line. At the conclusion of the sampling session, a final dynamic calibration was performed.

Carbon Monoxide--

Concentrations of CO were measured and recorded with a Beckman Model 865 infrared analyzer. The instrument operates on the principle of differential measurement of the absorption of infrared energy. The CO analyzer operated in the 0 to 50 ppm measuring range.

The first step in the Q/A program was the dynamic calibration of the analyzer before the actual sampling began. This was accomplished by employing zero air and three EPA-certified, compressed-gas tanks containing known concentrations of CO. A four-point calibration curve was then produced and recorded.

As the sampling program began, the analyzer was zeroed and spanned daily. The zero check was accomplished by introducing a source of zero air to the analyzer. A zero drift of more than $\pm 1.0\%$ of full scale from the reference calibration point would result in repair and recalibration of the instrument. A span check was conducted by diluting CO from a certified, compressed, aluminum tank with zero air to a known concentration. A span drift of more than $\pm 2.0\%$ of full scale from the reference calibration point was unacceptable. If the

span differed by this margin, the monitor was declared "inoperable," repairs were made, and a new reference calibration curve was generated.

At the conclusion of each 2-233k sampling session, the analyzer was dynamically calibrated with the zero air and the three EPA span gas tanks.

Ozone--

Concentrations of O_3 were constantly detected and recorded with a Meloy Model OA 350-2 analyzer. Its operation is based on the chemiluminescent reaction between O_3 and ethylene. The analyzer has a detection limit of 1.0 ppb and was operated in the 0 to 0.5 ppm range.

At the beginning of each sampling session, the analyzer was dynamically calibrated with the Meloy Model CNOS40 calibrator. This calibration established a zero and four up-scale concentrations of O_3 . Test concentrations of O_3 were generated using an ultraviolet O_3 generator calibrated by gas phase titration of NO.

As with the other continuous analyzers, the O_3 monitor was zeroed and span checked daily. This instrument was equipped with internal zero and span modes. Therefore, no external sources of span gas were necessary. Fluctuations of zero greater than $\pm 1.0\%$ of full scale or changes of span greater than $\pm 2.0\%$ of full scale from the reference calibration points required immediate maintenance and recalibration of the analyzer.

A dynamic calibration was performed on the analyzer at the conclusion of each 2-week sampling interval.

Sulfur Dioxide--

A Meloy Model SA 185-2A PFD SO₂ analyzer was employed in the study to measure and record levels of SO₂. This monitor provided continuous dry analysis of SO₂ through the use of the Flame Photometric Detection (FPD) technique. This patented technique monitors the intensity of light emitted by sulfur species passing through a hydrogen-rich flame. The manufacturer claims a detection unit of 0.004 ppm. The analyzer in this study operated in the 0 to 0.5 ppm measuring range.

Before the sampling session began, the SO₂ analyzer was dynamically calibrated with the Meloy Model CNOS40 calibrator. The calibrator contained an NBS traceable SO₂ permeation tube in a temperature-controlled environment. Output concentrations of SO₂ were dependent on the permeation rate of the tube and the flow rate of dilution air. Zero and four up-scale concentrations of SO₂ were established for this calibration.

Zero and span concentrations of SO₂ were introduced to the analyzer each day to determine changes, if any, in the calibration relationship. A certified (aluminum) cylinder of compressed SO₂, traceable to NBS standards, was the source of the daily span. This concentrated span gas was diluted to a constant daily concentration with a source of chemically zero air. A zero drift of greater than $\pm 1.0\%$ of full scale or a change in span of more than $\pm 2.0\%$ of full scale from the reference calibration points required immediate maintenance and recalibration.

A dynamic calibration was repeated after the 14-d session had been completed.

Total Hydrocarbons/Methane--

Total hydrocarbon and methane levels were detected with an MSA model 11-2 THC/CH₄ continuous analyzer. This analyzer operates on the principle of flame ionization. The instrument operates in the 0 to 100 ppm range for both parameters.

As with the other continuous gas analyzers, the THC/CH₄ monitor was dynamically calibrated before each sampling session. The calibration procedure was standard gas dilution. The calibration gas was certified by the manufacturer, AIRCO, as being traceable to NBS standards. It consisted of compressed CH₄ in an aluminum cylinder. This gas stream was mixed with zero air at variable flow rates to arrive at suitable concentrations. A calibration relationship was then constructed from the zero and four up-scale concentrations.

The analyzer was also zeroed and span checked daily. A known, constant concentration of methane was introduced to the analyzer after the zero check. The analyzer sampled this gas stream for 5 min. Zero and span variations of greater than $\pm 1.0\%$ and $\pm 2.0\%$ of full scale, respectively, were treated as described for the other analyzers.

When each sampling session was complete, the analyzer was again dynamically calibrated.

Wind Speed/Wind Direction--

Wind speed and wind direction measurements were made at a height of 9.1 m (30 ft) with a Bendix Aerovane Model 141/120. A signal was sent to a recorder inside the trailer, which constantly recorded both parameters.

Upon arrival at the sampling site, the mast was erected and secured. By using a compass, the north coordinate was determined, and the directional indicating vane was oriented in this direction. The wind speed indicator was checked for bearing wear and free, unbound movement. After the sampling session was complete, the orientation of the directional indicator was verified.

Temperature/Relative Humidity--

Temperature and relative humidity were constantly measured and recorded at each of the four sampling locations. These measurements were made with Weather Measure Corporation Model H-311 hygrothermographs. Temperature measurements were made by the use of a curved, bimetal strip that expanded or contracted as temperature fluctuated. Relative humidity was sensed by a bundle of human hair that expanded or contracted as relative humidity changed.

To insure collection of accurate data, the temperature sensors were calibrated against an ASTM (American Society of Testing and Materials) mercury thermometer before and after each 2-week sampling program. Likewise, the relative humidity

indicators were calibrated with a sling psychrometer before and after the sampling session. During the actual sampling activities, the recorder pens were visually inspected for proper alignment and ink supply.

Total Suspended Particulates--

Total suspended particulates were collected on 47-mm glass fiber filters at a flow rate of 84-112 l/min (3-4 ft³/min) for a period of 24 h. The filters were equilibrated at 25 °C and 40% RH for 24 h before they were weighed. The Perkin-Elmer auto balance was first zeroed, then calibrated with an NBS-certified 100-mg weight before each use. The filters were visually inspected for holes, tears, and creases and weighed to the nearest 0.01 mg. After the collection period, the filters were returned to the equilibration chamber for 24 h. When the equilibrium period was complete, the balance was zeroed and calibrated, and the filters were weighed to the nearest 0.01 mg. The data were then recorded in a logbook, and the filters were placed in sealed petri dishes and forwarded to the lab for additional analysis.

As an additional quality control step, a conventional high-volume sampler had been installed on the roof of the mobile lab. The sampler was operated every other day, and the results were compared against the ambient 47-mm filter.

Organic Vapors--

Organic vapors were collected daily on charcoal absorption tubes for a period of 24 h at a sampling flow rate of 200 cm³/min. A vacuum manifold in the mobile lab allowed for sampling at each of the four locations. At the completion of each 24-h sample, the charcoal tubes were placed in a refrigerator until they were shipped to the lab.

Flow control was achieved with calibrated hypodermic needles. For the purpose of quality control, the needles were calibrated after each sample with a soap bubble meter. The flow was corrected to standard conditions using the following equation:

$$Qs^1 = Qs \left[\frac{P_1}{760 \text{ mm Hg}} \times \frac{298K^\circ}{T_1 + 273^\circ} \right]^{1/2}$$

where:

Qs^1 = flow rate corrected to standard conditions

Qs = flow rate at field conditions

P_1 = barometric pressure at field conditions (mm Hg)

T_1 = temperature at field conditions (C°).

Aliphatic Aldehydes--

Sampling for aliphatic aldehydes was conducted daily at three interior locations per the following schedule:

- ° 0600 - 1000
- ° 1000 - 1400
- ° 1600 - 2000.

In addition, a fourth sampling train sampled the ambient location continuously. Two impingers, operated in series at a flow rate of 500 cm³/min, each containing 25 ml of MBTH, were used to collect aliphatic aldehydes. These needles were calibrated after each sample with a soap bubble meter. Flow rates were corrected to standard conditions using the following equation:

$$Qs^1 = Qs \left[\frac{P_1}{760 \text{ mm Hg}} \times \frac{298K}{T_1 + 273} \right]^{1/2}$$

where:

Qs^1 = flow rate corrected to standard conditions

Qs = flow rate at field conditions

P_1 = barometric pressure at field conditions (mm Hg)

T_1 = temperature at field conditions (C°).

General Quality Assurance (Q/A) Guidelines--

In addition to the specific Q/A procedures for each parameter, general procedures exist for maintaining the peripheral sampling equipment to further insure valid data.

Upon arrival at the lab, the field operators visually inspected all sampling lines for obstructions or kinks that would impair sampling efficiency. All pumps were inspected to insure that they were in proper operating condition. Recorders were checked for paper supply and ink capacity and were time-synched twice a day. All maintenance on each instrument was detailed in an instrument log. These additional Q/A procedures were vital to collecting accurate, constant data.

LABORATORY QUALITY CONTROL

Introduction

The laboratory Q/A program employed acceptable techniques to assure long-term accuracy and precision of methods and data. This program monitored and measured reliability in both methodology and instrumentation. Methodology was monitored by the continuous measurement of a standard reference material wherever practical and by replicate analysis of samples on a randomly selected basis. In addition, "standard reference" materials were obtained from the EPA Audit Program in Research Triangle Park, North Carolina, for sulfates, nitrates, and lead analysis. These reference materials were analyzed at a rate of one per seven samples in the case of sulfate and nitrates, and two per seven samples for lead, since the total number of lead samples analyzed at one time was considerably less than for the other two components. Instrumentation was monitored by the daily evaluation of performance standards.

Instrumental Reliability

Since all methods with the exception of lead and organic determination employed colorimetric procedures, the spectrophotometer was monitored by the measurement of a special spectrophotometric function test solution. The absorbency as a function of relative color intensity was measured, and the slope and intercept were determined by linear regression analysis. The slope and intercept were plotted on a performance

chart (Figure 71). Past experience has shown that the slope does not vary by more than $\pm 2\%$ and the intercept by more than ± 0.002 absorbency units. Whenever the slope and/or intercept varied by more than these values on two consecutive days, the spectrophotometer was serviced by cleaning the optical system. If no improvement was effected by in-house preventive maintenance, the instrument was serviced by the manufacturer or his representative.

No reliability techniques are available that can be applied to the day-to-day operation of the gas chromatograph for the determination of organics or the atomic absorption spectrometer for the analysis of lead.

Accuracy and Precision of Methods

Accuracy and precision of the analytical methods were evaluated by the use of standard reference solutions and by the results of duplicate analysis of randomly selected samples. Duplicate analyses were outdone on a 10% basis; that is, 1 of every 10 samples was duplicated. Accuracy of each method was charted on a performance chart evaluating percent recovery of the standard reference solution. Precision was charted on a performance chart evaluating both percent deviation of the mean and range of duplicates (see Figures 72 and 73).

WAVELENGTH _____ NM

[illegible]

Figure 71 Spectrophotometer function test

PERCENT DEVIATION AND RANGE CHART

PROJECT NAME _____		ANALYSIS _____										UNITS _____									
DATE																					
VALUE 1																					
VALUE 2																					
RANGE																					
MEAN																					
% DEVIATION																					
PERCENT DEVIATION FROM MEAN																					
RANGE																					

Figure 72. Percent deviation and range chart.

PROJECT NAME _____ ANALYSIS _____ UNITS _____

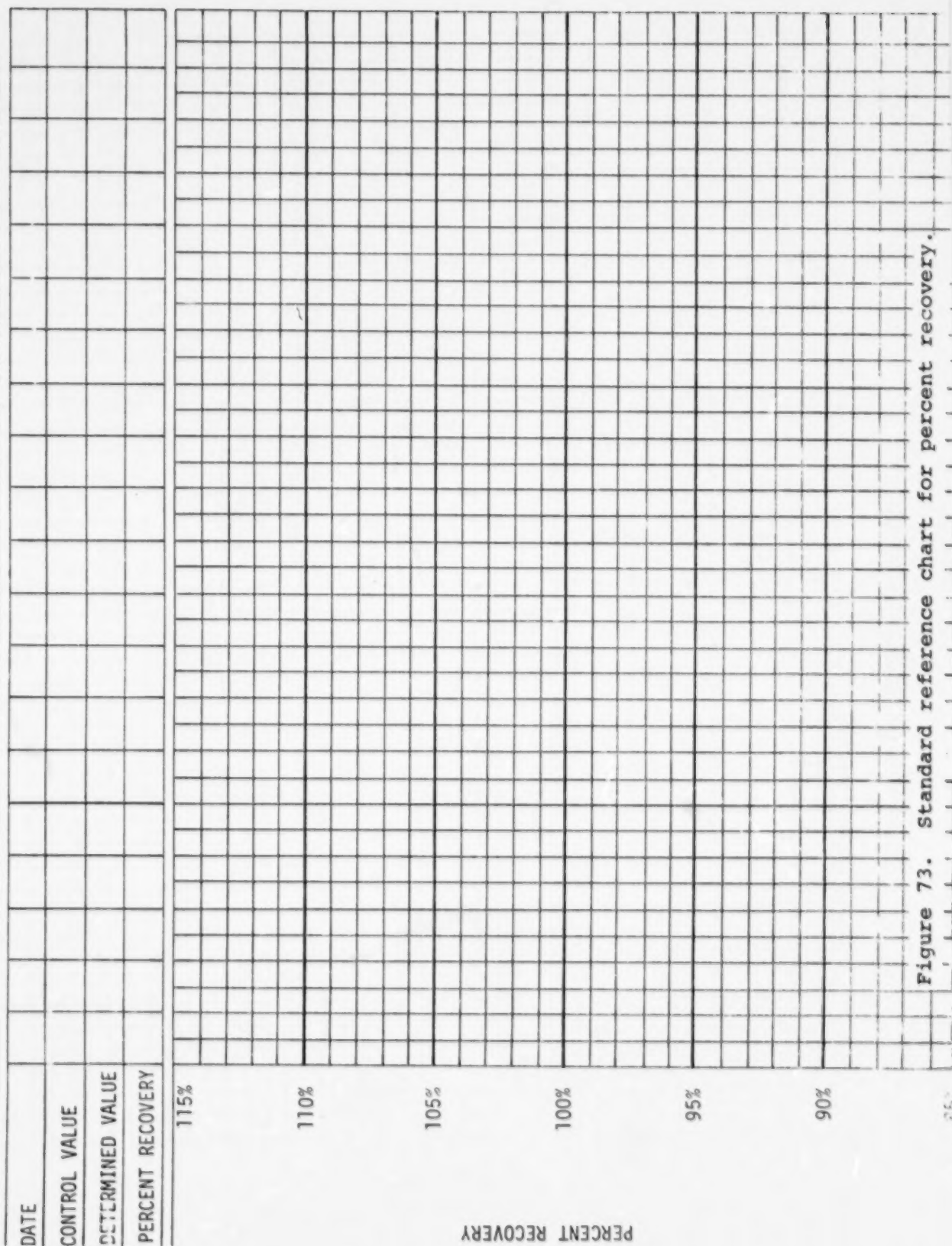


Figure 73. Standard reference chart for percent recovery.

Standard reference solutions utilized in this study were prepared from primary standard grade materials. Whenever a standard reference solution could not be utilized because of deterioration of it or its substrate, such as in the case of aldehydes in which the trapping solution (MBTH) is unstable for prolonged periods, a dilution of the highest reference standard was prepared by a person other than the analyst and introduced into the analysis scheme as a reference solution. The result of this value was handled in the same manner as a standard reference solution.

Specific Procedures

Ammonia--

The accuracy of the ammonia method was measured by the continuous analysis of an ammonium sulfate standard reference solution. A stock solution in the range of 1-3 mg/l ammonia as ammonium sulfate (Primary Standard) was prepared. An aliquot of this standard was measured at least once with every set of ammonia analyses. A continuing record of ammonia found to ammonia added (percent recovery) was maintained.

Nitrate--

The accuracy of the nitrate procedure was evaluated by the continuous analysis of a potassium nitrate standard reference solution. A stock standard reference solution in the range of 2-4 mg/l of nitrate as potassium nitrate (Primary Standard) was prepared. An aliquot of the standard reference solution was measured at least once with every set of nitrate analyses.

A continuing record of nitrate found to nitrate added (percent recovery) was maintained.

Sulfate--

The accuracy of the sulfate method was established by the continuous analysis of a sulfate standard reference solution. A stock solution in the range of 5-15 mg/l sulfate as ammonium sulfate was measured at least once with every set of sulfate analyses. A continuing record of sulfate found to sulfate added (percent recovery) was maintained.

Aldehydes--

No long-term standard reference material could be prepared that would monitor the accuracy of the method on a long-term basis. At best, a standard solution of these organics of interest was always run concurrent with each batch of samples. Duplicate analyses were performed on a random basis to determine the precision of the method.

Organics--

No standard reference material could be prepared that would monitor the accuracy of the method on a long-term basis. At best, a standard solution of these organics of interest was always run concurrent with each batch of samples. Duplicate analyses were performed on a random basis to determine the precision of the method.

Lead--

An aliquot of a certified reference solution of 1,000 mg/l was diluted with the acid to achieve a concentration range of the order of 1-5 mg/l. This standard reference material was run once with every set of unknown samples. Percent recovery was charted on a performance chart. Duplicate analyses of randomly selected samples were made on a 10% frequency rate.

DATA MANAGEMENT QUALITY CONTROL

In order to eliminate as many potential errors as possible, certain checks and procedures were built into the data management phase of this project. Following is a brief description of the procedures employed in order to assure the quality of the data produced.

Continuous Data

The strip charts for NO, NO_x, CO₂, CO, O₃, SO₂, CH₄, THC, wind speed/direction, temperature, and relative humidity were reduced by the field operator, and the percent of scale was listed on the Pollutant Analysis Input Form (Figure 58). The form was screened for completeness by the data coordinator prior to auditing. After the form had been screened, an individual other than the person who reduced the strip chart performed an audit of the data as it appeared on the strip chart versus the value that appeared on the reduction form. For the eight continuously monitored gaseous pollutants, the auditor selected the maximum value and a random value for each parameter from each 24-h period and compared his interpretation of the strip chart with the original value. A difference of $\pm 2.0\%$, or greater, initiated a reevaluation of the entire chart. The temperature, relative humidity, wind speed, and wind direction charts were audited in the same manner. The control limits for these parameters were as follows:

- ° Temperature $\pm 2.0^\circ$
- ° Relative humidity $\pm 2.0\%$

- Wind speed ± 53.6 m/s (2.0 mph)
- Wind direction $\pm 10.0^\circ$.

As part of the keypunching process, the cards were verified. This is a process whereby the cards are fed through another keypunch machine and a different person keypunches the data listed on the Pollutant Analysis Input Form. The machine electronically compares what is being keyed with the information already on the card. If a difference occurred, the machine "jammed" and the discrepancy was checked and corrected. Once fed into the computer, the data were automatically screened for outliers. The minimum values were the detection limits of the analytical method; the maximum values were arbitrary concentrations somewhat higher than the levels expected for monitoring in the planned environments. Table 8 lists the minimum and maximum values anticipated for this project. Outliers were not necessarily incorrect, but this system of flagging them prevented inclusion of data that could bias the statistical computations.

To eliminate as much human error as possible, the computer calculated the slope and intercept of the standard curve, using the method of least squares, from the calibration data from (Figure 61). The difference between the observed and calculated concentrations was determined, and the standard deviation computed. All differences greater than twice the standard deviation were rejected, and a new slope, intercept, and standard deviation were determined (see Figure 66). Using these

values, the percent of scale supplied by the operator was converted to a concentration (either ppm or ppb).

TABLE 8. SCREENING VALUES FOR MONITORING DATA

Parameter	Detection limit	Maximum expected
NO	5 ppb	200 ppb
NO ₂	5 ppb	200 ppb
CO ₂	25 ppm	2000 ppm
CO	0.5 ppm	10 ppm
O ₃	5 ppb	100 ppb
SO ₂	5 ppb	100 ppb
CH ₄	0.2 ppm	10 ppm
THC	0.2 ppm	10 ppm

Since the data were summarized to some extent in the data output, requirements were set for the amount of valid data required for summarization. Table 9 lists the required criteria for summarizing data.

The wind speed/direction, temperature, and relative humidity charts were reduced by the field operator and submitted to the data coordinator on Form 3252-2 (Figure 59). The procedures previously described were followed except that no conversion from one unit to another was required for the data.

TABLE 9. CRITERIA FOR COMPLETENESS FOR CONTINUOUS AMBIENT AIR MONITORS

Time Interval	Minimum number of observations
1 h running average	3 Consecutive 20 min observations
3 h running average	3 Consecutive hourly observations
8 h running average	6 Hourly observations
24 h running average	18 Hourly observations
Monthly	21 Daily averages
Quarterly	3 Consecutive monthly averages
Yearly	9 Monthly averages with at least two monthly averages per quarter

Intermittent Data

The analytical results of intermittent samples were submitted to the data coordinator on the 24-h sampling interval form (Figure 60). As with the continuous data, the data coordinator checked the form for completeness prior to keypunching. The keypunched cards were verified, and the data were screened by the computer for outliers. Table 10 illustrates the minimum and maximum limits for the indicated parameters.

TABLE 10. SCREENING VALUES FOR DETECTION OF OUTLIERS

Parameter	Detection limit	Maximum value expected
Total suspended particulate	$0.1 \mu\text{g}/\text{m}^3$	$500 \mu\text{g}/\text{m}^3$
Respirable particulate	$0.1 \mu\text{g}/\text{m}^3$	$500 \mu\text{g}/\text{m}^3$
Organic vapors	ppb as CH_4	--
Aliphatic aldehydes	$1.5 - 5 \mu\text{g}/\text{m}^3$	$100 \mu\text{g}/\text{m}^3$
Ammonia	$5 \mu\text{g}/\text{m}^3$	$100 \mu\text{g}/\text{m}^3$
Sulfates from TSP samples	$0.5 \mu\text{g}/\text{m}^3$	$20 \mu\text{g}/\text{m}^3$
Nitrates from TSP samples	$0.1 \mu\text{g}/\text{m}^3$	$5 \mu\text{g}/\text{m}^3$
Lead from TSP samples	$0.005 \mu\text{g}/\text{m}^3$	$5 \mu\text{g}/\text{m}^3$

TOTAL SYSTEM--AUDIT FUNCTION

To realize maximum benefits from an auditing program, it must necessarily be conducted independently of the routine operation of the sampling network. Furthermore, the audit should be a true check of the measurement process under normal operation, i.e., without any special preparation or adjustment of the system. Independence can be achieved by having the audit made by an operator/analyst different from the one conducting the routine field measurements.

The Guidelines for Development of a Quality Assurance Program promulgated by the U.S. Environmental Protection Agency contain auditing procedures for those ambient parameters having primary and secondary standards. Since some of the parameters of interest in this study do not have prescribed auditing procedures, we have tried to extrapolate the established procedures for all of the parameters.

Field Audits

Table 11 summarizes the parameters and the type of audits to be performed relative to each measurement. Since a particular audit type is the same for all parameters, we will discuss them by audit type.

Flow Rate Audit--

During each approximate 2-week sampling period, the monitors for total suspended particulate had the measured flow checked by means of a calibrated dry gas meter. The percent

TABLE 11. SUMMARY OF AUDITS

	Flow rate audit	Data processing audit	Control sample audit	Water vapor interference audit	Clean filter weighing audit	Exposed filter weighing audit
NO/NO _x		X	X			
CO/CO ₂		X	X	X		
O ₃		X	X			
SO ₂		X	X			
CH ₄ /THC						
Wind Speed/Direction						
Temperature						
Relative humidity						
Total suspended particulate	X	X			X	X
Organic vapors		X	X			
Aldehydes		X	X			
Nitrate		X	X			
Lead		X	X			
Sulfate		X	X			

difference was calculated by means of the following equation:

$$D = \frac{F_m - F_a}{F_a} \times 100$$

where:

D = difference (percent

F_m = the flow measured by the routine operator

F_a = the audit flow measured with the calibrated dry gas meter.

Any difference greater than 7% required a complete recalibration of the entire sampling train including the rotameter and critical orifice, when applicable. Organic vapors and aldehyde monitors use critical orifices that require calibration before every sampling period.

Clean Filter Weighing Audit--

Normally, about 20 clean filters are weighed in one lot. The other technician in the trailer reweighed 4 out of each lot of 50 or less. The audit weights were recorded in the filter log book alongside the original weights. Any difference greater than +0.2 mg required that all filters in the lot be reweighed.

Exposed Filter Weighing Check--

Normally, exposed filters are weighed in lots of four. Each time, the other technician reweighed one of the four filters and recorded the audit weight alongside the original weight in the filter record book. Any difference greater than +0.5 mg required that the entire lot be reweighed.

Control Sample Audit--

For the continuous monitors, NO/NO_x , CO/CO_2 , O_3 , SO_2 , and CH_4/THC , a reference sample audit was performed by the U.S. Environmental Protection Agency during the initial phase of the project. For organic vapors and aldehydes, there was no technique for our application. For analysis of nitrate, lead, and sulfate, a sample prepared by the laboratory was introduced into the regular lot of samples. This control sample was analyzed in the same manner as the "field" samples, and the results reported to the supervisor of the laboratory. If any difference greater than 10% occurred, the analysis was stopped, checks were made to determine the assignable cause(s), and corrective action was taken. The frequency was 7 audits for lots of 100 samples or 4 for lots of 50 samples or less. Control charts, such as Figure 73, were maintained for each of the three parameters.

Post-Sampling Audits

Data Processing Audits--

Data processing audits were performed at a level of 4 per lot of 50. For continuous data, it is generally acceptable to check two 24-h periods from each day rather than four 24-h periods out of each 50 d. An independent technician read the highest and one other nonzero value from each 24-h period and recorded the results in a log as illustrated in Figure 74. The check was made starting with the strip chart record and

DATA AUDIT CHECK

City _____ Site No. _____
 Site location _____ Pollutant _____
 Date _____ Operator _____
 Checker _____ Date _____

Hour	Reading		Zero baseline		Difference		Add + 5		ppm	
	Original	Check	Original	Check	Original	Check	Original	Check	Original	Check

Comments: _____

City _____ Site No. _____
 Site location _____ Pollutant _____
 Date _____ Operator _____
 Checker _____ Date _____

Hour	Reading		Zero baseline		Difference		Add + 5		ppm	
	Original	Check	Original	Check	Original	Check	Original	Check	Original	Check

Comments: _____

Figure 74. Data audit check sheet.

continuing through the actual transcription of the concentration in ppm on the computer printout. If either one of the two checks differed by as much as +1 ppm from the respective original value, all hourly averages for that sampling period were checked and corrected.

Chapter 2

DATA REPORTS FOR EPISODIC RELEASE EXPERIMENTS*

PITTSBURGH SAMPLE SETS

Sampling

The methodology for collecting organic contaminants associated with the episodic release experiments was developed by the IIT Research Institute under the direction of Dr. A. Dravnieks with the support of ASHRAE Research. The samples taken from the release of a scented oven cleaner in the Pittsburgh Hi-Rise Apartment I are identified in Table 12. Solid adsorbent sampling was employed. The samplers contained 90 mg of Tenax GC sorbent.

TABLE 12. SAMPLE IDENTIFICATION

		Location	Air volume sampled (cm ³)
Set I	-	Started Simultaneously	
		Living Room	2000
		Bath Room	2000
		Kitchen ^a	340
		Hall ^a	360
		Ambient ^a	2000
		Ambient ^b	2000
Set II	-	Started 15 min later	
		Kitchen ^b	370
		Hall ^b	350

* Prepared by IIT Research Institute, Project Manager - Dr. Andrew Dravnieks.

^a Background components contributed to the total peak area.

^b Estimated concentration; integrator malfunction.

Analysis

All samples were analyzed by the combined technique of gas chromatography-mass spectrometry (GC-MS). The sampler was injected into the carrier gas flow of the GC at the injection port. By rapidly heating the sampler (240 °C) while reverse flushing with carrier gas, the sample was injected directly onto the GC column for analysis. A 15.25 m (50 ft) x 0.5 mm (0.020 in.) i.d. SP 1000 SCOT column was used, under a temperature program of 50 ° to 200 °C at 6 °C/min.

The column effluent was split (1:1) between a flame ionization detector and the mass spectrometer. The FID response was used to obtain the quantitative sample data. The FID signal was integrated by a Hewlett-Packard 2380 electronic integrator and calibrated with n-alkane standards covering the range of the sample chromatogram, C₈-C₂₂.

The other portion of the column effluent passed through a two stage Biemann-Watson separator and into the ion source of the mass spectrometer, a Varian MAT 311A. The mass spectrometer was operated in a continuous, repetition scan mode for the duration of the analysis with computer data acquisition (Spectro System 100MS).

A particular concern in survey analysis by GC-MS of very small samples, 350-2000 cm³, is the background contributed by the analysis system. The principal source of the background for the analysis is the Tenax GC material. The species contributed by Tenax GC during thermal sample elution are minimal, nanogram amounts, but organic species in air are at the same concentration, generally ppb by weight or nanograms per liter. Thus the analysis background is not negligible for samples of this size. Several background analyses were run with each sample set, under conditions identical to those used for the sample analyses. These data were used to evaluate sample data and eliminate background artifacts.

Results

Sample analysis data are presented in Tables 13 to 18. Several factors should be noted in evaluating the results presented:

1. Concentration estimates in parentheses are species whose retention volumes in the sampler are exceeded by the volume of air sampled. Therefore, they are not quantitatively collected. This is most apparent with the concentrations reported for the butane propellant. The smaller samples (350 cc), extrapolated to 1000cc concentrations, represent more accurate values. Since the light aliphatic hydrocarbons, up to C_9 , are of minimal interest, neither the sampling techniques nor the analysis technique was designed to emphasize this lower range of the organic air component survey.
2. Concentration estimates with the superscript "a" denote peaks containing multiple components. Often the other species were background components. Multiple components are detected from the mass spectral data but exact quantitative relative concentrations cannot be determined.
3. At least 13 components can be directly related to the scented oven cleaner. They are summarized in Table 18. Most of these, the terpenes, are components of the odorant. In both the Hall and Kitchen samples, higher concentrations were detected in the samples taken 15 min later.
4. The four Hall and Kitchen samples were $\sim 350\text{-cm}^3$ samples, and the concentrations of many of the odorant species were below detection limits. The data were extrapolated to 1000 cm^3 for comparison with the 2000 cm^3 samples. Comparable 200 cm^3 samples in the Hall and Kitchen would have provided better qualitative surveys.
5. Benzene and toluene are two of the main Tenax-contributed artifacts. They obscure sections of the chromatogram for quantitative data on other components. The background concentrations of these species are higher than normal ambient sample concentrations, so their presence in the samples is difficult to ascertain.

TABLE 13. AMBIENT AIR

Retention Time (min.)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
		C ₅ alkane
		C ₆ alkane
		C ₆ alkene
		C ₇ alkanes
		C ₇ alkenes
		C ₈ alkene
		(benzene)
		(toluene)
3.6	10 ^a	tetrachloroethylene
~5.0	0.4	C ₁₀ alkane
~5.8	3	ethylbenzene
~6.0	4	xylene
6.8	2	xylene
7.5	0.2	n-propylbenzene
7.9	0.5	C ₃ alkylbenzene (methylethyl-or isopropyl-)
9.0	0.8	trimethylbenzene
9.8	2	C ₃ and C ₄ alkylbenzenes
10.7	0.5	C ₄ alkylbenzene
11.2	0.2	C ₁₃ alkane
11.5	<0.2	possible furfural
11.8	0.3	C ₅ alkylbenzene
12.8	4 ^a	Pyrrole
14.2	<0.1	possible methylpyrrole
14.5	0.1	possible methylfurfural

^aComponent mixture present; some background contribution to total peak area.

TABLE 14. LIVING ROOM

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
0.6	(197)	n- and -iso-butanes, trace of Freon 11
0.9	(24)	{ C ₅ alkane C ₆ alkane C ₆ alkene
1.1	(21)	{ C ₇ alkane C ₇ alkene
1.3	(24)	C ₈ alkane
1.5	(13)	furan
1.6	(23)	{ C ₈ alkene acetone
1.8	19	{ C ₈ alkene methylfuran (benzene)
3.4	20 ^a	tetrachloroethylene
3.6	31 ^a	{ (toluene) terpene, 136 M ⁺
4.4	0.4	terpene, 136 M ⁺
5.1	10	β-pinene
5.4	3	ethylbenzene
5.6	1	xylene
5.8	0.6	terpene and alkane
6.48	unresolved shoulders main component	{ xylene terpene - probable myrcene unidentified, 154 M ⁺
6.9		limonene
7.6	7	C ₃ alkylbenzene
7.9	12	terpene - possible phellandrene or terpinene
8.4	4	t-butylbenzene
8.5	2	trimethylbenzene
8.7	12	terpinolene
9.1	0.3	C ₄ alkylbenzene
9.6	0.2	C ₃ and C ₄ alkylbenzenes
10.6	2	C ₄ alkylbenzene and probable alkane
11.7	est ~150 ^b	dichlorobenzene (trace of furfural)
12.6	2	C ₁₄ alkane
12.9	5 ^a	pyrrole
14.1	1	methylpyrrole
14.5	6	C ₁₅ alkane, trace of methylfurfural
15.1	3	terpene or derivative
16.8	2	probable terpene oxygenate
17.5	~11	naphthalene
19.0	98	unidentified oxygenate (possible dioxolane derivative or oxy alcohol)
19.9	5	methylnaphthalene
20.6	0.5	methylnaphthalene

^aComponent mixture present; some background contribution to total peak area.

^bEstimated concentration; integrator malfunction.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 15. BATHROOM

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
0.7	(347)	{ n- and iso-butanes, main component C ₄ alkene C ₅ alkene C ₆ alkene C ₇ alkane
1.3	(2)	{ C ₇ alkene C ₈ alkane
1.6	(15)	acetone
1.9	3	C ₈ alkane
2.1	5	{ C ₉ alkene C ₈ alkene (benzene)
3.5	8 ^a	tetrachloroethylene
3.7	11 ^a	{ (toluene) terpene, 136 M ⁺
4.0	est. 1	C ₁₀ alkane, trace of C ₁₀ alkene
4.4	2	terpene, 136 M ⁺
5.2	10	β-pinene
5.5	3	ethylbenzene and xylene
5.7	6	{ xylene C ₁₁ alkane terpene, 136 M ⁺
6.6	unresolved shoulders main component 9	{ myrcene xylene unidentified, 154 M ⁺
7.0	122	limonene
7.7	3	C ₃ alkylbenzene
8.0	7	terpene, 136 M ⁺
8.4	3	C ₄ alkylbenzene
8.6	1	C ₃ alkylbenzene
8.7	12	terpinolene
9.2	<0.5	C ₄ alkylbenzene
9.6	<0.5	C ₃ alkylbenzene
10.7	2	C ₁₃ alkane
11.7	393	dichlorobenzene
12.7	1	C ₁₄ alkane
14.6	2	C ₁₅ alkane
16.3	1	C ₁₆ alkane
16.8	2	probable terpene oxygenate
17.5	~10	naphthalene
19.1	87	unidentified oxygenate (possible dioxolane derivative or oxy alcohol)

^aComponent mixture present; some background contribution to peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 16. KITCHEN, A AND B SAMPLES

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
Kitchen b - 370 cm ³		
0.7	(2400)	n- and iso-butanes
1.3	(47)	C ₇ alkene
1.6	(114)	C ₆ alkene
2.1	59	acetone
		C ₈ alkene, possible methylfuran (benzene)
3.6	61 ^a	tetrachloroethylene
		terpene, 136 M ⁺ (toluene)
4.3	~0.5	terpene, 136 M ⁺
5.3	5	β-pinene
5.7	~1	xylene
		terpene
6.7	22	xylene
		unidentified, 154 M ⁺
7.2	189	limonene
7.4	5	C ₃ alkylbenzene
8.2	19	terpene and C ₄ alkylbenzene
8.6	22	C ₄ alkylbenzene
8.9	14	terpinolene and C ₄ alkylbenzene
11.9	246	dichlorobenzene, trace of furfural
13.1	14	pyrrole
14.4	5	methylpyrrole
17.7	7	naphthalene
19.4	14	unidentified oxygenate
19.7	7	methylnaphthalene
Kitchen a - 340 cm ³		
0.7	(2300)	n- and iso-butanes
2.5	(120)	acetone
5.3	<1	terpene, 136 M ⁺
6.3	<1	C ₂ alkylbenzene
7.4	25	limonene
8.7	~1	aromatic
9.0	~1	terpene
9.7	~1	C ₄ alkylbenzene
12.0	26	dichlorobenzene
13.0	8	tetrachloroethane and pyrrole

^a Background components contributed to the total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 17. HALL, A AND B SAMPLES

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
Hall b - 350 cm ³		
0.7	(2600)	n- and iso-butaness
1.3	(80)	C ₆ and C ₇ aliphatics
1.5	(90)	acetone
2.3	<1	C ₈ alkene (benzene) (toluene)
4.5	12	terpene, 136 M ⁺
4.9	3	C ₂ alkylbenzenes
5.7	<1	xylene
6.6	6	unidentified, 154 M ⁺
6.9	111	limonene
7.4		trace of C ₃ alkylbenzene
8.3	2	C ₄ alkylbenzene
8.7	9	terpinolene
9.4	1	C ₄ alkylbenzene
11.7	122	dichlorobenzene
12.7	10 ^a	pyrrole
14.0	2 ^a	methylpyrrole
16.2	4	C ₁₆ alkane
Hall a - 360 cm ³		
0.7	(2400)	n- and iso-butaness
1.5	(90)	acetone
2.3	<1	C ₈ alkene (benzene) (toluene)
6.3	<1	C ₂ alkylbenzene
7.4	28	limonene
11.9	44	dichlorobenzene
12.9	13 ^a	pyrrole
13.9	<1	methylpyrrole
16.6	5	C ₁₆ alkane

^a Background components contributed to the total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 18. SUMMARY OF RELEASE RELATED SPECIES

	(10 ⁻⁹ g/l)				
	Living Room (2000 cm ³)	Bathroom (2000 cm ³)	Kitchen-a (340 cm ³)	Hall-a (360 cm ³)	Hall-b (350 cm ³)
A Terpene	31 ^a	11 ^a	-	-	-
B Terpene	0.4	2	-	-	-
C β -pinene	10	10	<1	-	2
D Terpene	0.6 ^a	6	-	-	-
E Terpene-myrcene	11	9	-	-	-
F 154 M ⁺ , unidentified			-	22	6
G Limonene	144	122	25	28	111
H Terpene terpinene	12 ^a	7	-	-	-
I Terpene-terpinolene	12	12	<1	-	9
J Dichlorobenzene	est. 150	393	26	44	122
K Terpene or derivative	3	-	-	-	-
L Terpene-oxygenate	2	2	-	-	-
M Unidentified oxygenate	98	87	-	-	14

^aComponent mixture present; some background contribution to total peak area.

Discussion

The concentration data are presented as estimates. These analyses are primarily concerned with obtaining good qualitative surveys. Their primary objective is not absolute quantitative data. It is suggested that the quantitative data be taken as reliable to within an order of magnitude of the absolute value for any component.

These data indicate that the analysis technique is suitable for detecting species at ppb concentrations. If components in the range of 1-10 ppb are of interest, the 2000 cm³ sample size is required.

PITTSBURGH SAMPLE SETS II and III

Sampling and Analysis

Tables 19-29 contain sample data from the Pittsburgh Hi-Rise Apartments II and III. The Pittsburgh II Sample Set, taken after release of an unscented aerosol deodorant, is identified in Table 19. Table 25 lists the samples of the Pittsburgh III Set, where a scented aerosol furniture polish was released. The experimental details of the analysis procedures employed were described earlier in this chapter.

Results

Tables 20 through 25 contain the data from the Pittsburgh II samples. All concentration estimates are given in 10^{-9} g/l for relative comparison of data from the 2-1 samples and the smaller samples (280-350 cm³). The extrapolated concentration values for the small samples are less accurate in the $1-10 \times 10^{-9}$ g range since this is close to the detection limit of the analysis. The values in parentheses are those species for which the volume of air sampled exceeds the specific retention volume. In these cases, the smaller samples represent more accurate values. The "a" superscript denotes instances where background components identified from "blank" analyses and detected in the samples from the mass spectral data, contribute to the area of a sample component peak.

As reported previously, concentration estimates are calculated using the flame ionization detector response to the series of n-alkanes covering the range of the chromatograms. Since the n-alkane response is significantly different from the FID response to Freons, the specific response factor for Freon 11 was obtained and used to calculate the concentration estimates.

The sample data from the Pittsburgh-III samples are listed in Tables 27 and 28. Table 27 presents the data from the 2-1

TABLE 19. SAMPLE IDENTIFICATION
(Pittsburgh-II Sample Set)

Location	Air volume sampled (cm ³)
Started simultaneously, 2:12 pm:	
Bedroom ^a	2000
Living Room	2000
Bathroom	280
Hall ^a	350
Ambient-Outside	2000
Started 2:34 p.m.:	
Bedroom ^b	350
Started 2:39 p.m.:	
Hall ^b	340

^aBackground components contributed to the total peak area.

^bEstimated concentration; integrator malfunction.

TABLE 20. AMBIENT AIR SAMPLES--OUTSIDE
(2000 cm³)

Retention time (min)	Concentration estimate (10 ⁻⁹ g/l)	Mass spectral data
0.9	(24)	C ₆ alkane, C ₆ alkene, C ₇ alkane
1.1	(5)	C ₇ alkene, C ₈ alkane
1.3	(2)	acetone
1.7	(1)	C ₈ alkene
2.1	-	(benzene)
3.3	-	trace tetrachloroethylene
3.5	-	(toluene)
5.3	0.4	ethylbenzene, xylene
5.5	2	xylene
6.4	0.6	xylene
6.9	0.8	chlorobenzene
7.1	0.8	n-propylbenzene
7.4	0.7	C ₃ alkylbenzene (methylethyl- or isopropyl-)
7.8	3	trimethylbenzene
8.6	2	trimethylbenzene
10.1	0.4	C ₄ alkylbenzene
10.8	0.2	C ₃ and C ₄ alkylbenzenes
12.2	5	furfural
13.0	4	pyrrole and furylmethylketone

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 21. BEDROOM-a SAMPLES
(2000 cm³)

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass spectral data
0.8	(6100)	Freon 11 (trichlorofluoromethane)
1.1	(21)	C ₅ alkene, C ₆ alkane, C ₆ alkene, C ₇ alkane, C ₇ alkene
1.3	(26)	C ₈ alkane, C ₇ alkene
1.7	(36)	C ₈ alkene, acetone, C ₉ alkane
2.3	12	C ₉ alkene
2.5	14 ^a	(benzene), C ₉ alkane, C ₉ alkene
2.6	10	C ₁₀ alkane
2.8	-	trace trichloroethylene
3.2	-	trace tetrachloroethylene
3.7	-	(toluene)
5.4 } 5.7 }	22	xylene, C ₁₁ alkane, trace terpene (136 M ⁺)
6.2	6	xylene
6.9	27 ^a	limonene
7.2	4	C ₃ alkylbenzene (methylethyl- or isopropyl-)
7.7	3	trimethylbenzene
8.0	0.8	C ₃ alkylbenzene
8.4	0.3	C ₄ alkylbenzene
8.5 } 9.1 } 9.3 }	4	trimethylbenzene
	2	C ₄ alkylbenzenes
9.6 } 9.8 }	2	C ₃ and C ₄ alkylbenzenes
10.1	2	C ₄ alkylbenzene, C ₅ alkylbenzene
10.5	0.7	C ₄ alkylbenzene
10.8	0.3	C ₄ and C ₅ alkylbenzenes
11.2	0.3	C ₅ alkylbenzene
11.6	0.9	C ₄ alkylbenzene
11.8	5	dichlorobenzene, trace C ₆ alkylbenzene
12.2	5	furfural
13.0	4 ^a	pyrrole
14.2	1	alkane
16.2	2	C ₁₆ alkane
17.5	3	naphthalene
19.6	1	methylnaphthalene
20.2	0.3	methylnaphthalene

^a Background components contributed to the total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 22. BEDROOM-b SAMPLES
(350 cm³)

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
0.9	(30,000)	Freon 11 (trichlorofluoromethane), trace of Freon 12 (dichlorodifluoromethane)
1.3	(44)	C ₆ alkene, C ₇ alkene, C ₈ alkane
2.0	(49)	C ₈ alkene, acetone
2.2	-	(benzene)
2.3	49 ^a	C ₉ alkane
2.7	-	C ₉ alkane, C ₉ alkene
3.0	-	trace trichloroethylene
3.6	-	(toluene)
5.5	2	ethylbenzene
5.8	7	xylene, trace C ₁₁ alkane
6.4	~2	xylene
7.2	a	limonene
7.6	~2	C ₃ alkylbenzene, C ₁₂ alkane
7.9	3	C ₃ alkylbenzene
8.7	5	C ₃ alkylbenzene
9.3	~1	C ₄ alkylbenzene
9.5	~1	C ₄ alkylbenzene
9.7	~1	C ₄ alkylbenzene
9.9	~1	C ₃ alkylbenzene
10.3	~1	C ₄ alkylbenzene
12.3	7	furfural
13.1	11	pyrrole, furylmethylketone
14.2	3 ^a	methylpyrrole
14.7	<0.5	methylfurfural

^aBackground components contributed to the total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 23. LIVING ROOM SAMPLES
(2000 cm³)

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
0.9	(3400)	Freon 11 (trichlorofluoromethane)
1.0	(13)	C ₇ alkane
1.2	(11)	C ₇ alkene, C ₈ alkane
1.4	(31)	C ₈ alkene, acetone
1.9	15	C ₉ alkene
2.0	23 ^a	(benzene)
2.3		C ₉ alkane
2.6		trace trichloroethylene
3.2	~4	tetrachloroethylene
3.5		(toluene)
5.2	5	ethylbenzene
5.5	21	xylene main, C ₁₁ alkane, C ₁₁ alkene, trace terpene (136 M ⁺)
6.4	8	xylene
7.0	16	limonene
7.4	8	C ₃ alkylbenzene (methylethyl- or isopropyl-)
7.9	9	trimethylbenzene, alkane
8.6	5	trimethylbenzene
9.0	2	C ₄ alkylbenzene
9.2	4	C ₄ alkylbenzene (n- or isopropyl-)
9.7	1	C ₃ and C ₄ alkylbenzenes
10.2	2 ^a	C ₁₃ alkane
10.3	1	C ₄ alkylbenzene
11.3	~2 ^a	C ₄ and C ₅ alkylbenzenes
11.8	5	dichlorobenzene
12.3	6	furfural main, C ₁₄ alkane
13.0	5 ^a	pyrrole main
14.2	0.4	methylpyrrole
14.3	2 ^a	C ₁₅ alkane
16.3	~2	probable alkane
17.5	4	naphthalene
19.6	1	methylnaphthalene
20.2	0.6	methylnaphthalene

^a Background components contributed to the total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 24. BATHROOM SAMPLES
(280 cm³)

Retention time (min)	Concentration estimate (10 ⁻⁹ g/l)	Mass spectral data
0.8	(376,000)	Freon 11 (trichlorofluoromethane), trace of Freon 12 (dichlorodifluoromethane)
1.4	(2)	acetone
2.0	(34)	dichloromethane
3.4	-	(toluene)
5.2	-	C ₂ alkylbenzene
5.5	6	xylene
6.4	2	C ₃ alkylbenzene
6.9	2	C ₄ alkylbenzene
7.2	7	C ₃ alkylbenzene
7.8	1	C ₄ alkylbenzene
9.0	1	dichlorobenzene
9.4	3	furfural

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 25. HALL SAMPLES

Retention Time (min)	Concentration Estimate (10 ⁻⁹ g/l)	Mass Spectral Data
Hall-a (350 cm ³)		
0.8	(29,000)	Freon 11 (trichlorofluoromethane), trace of Freon 12 (dichlorodifluoromethane)
1.4	(27)	C ₈ alkene, acetone
2.1	-	(benzene)
2.8	-	trace trichloroethylene
3.4	-	(toluene)
5.2	2	ethylbenzene
5.5	3	xylene
6.3	3	xylene
7.4	2	C ₃ alkylbenzene
7.9	14	C ₃ and C ₄ alkylbenzenes
8.6	7 ^a	C ₃ alkylbenzene
8.9	3	C ₃ and C ₄ alkylbenzenes
11.8	39	dichlorobenzene
12.5	3	furfural
13.0	11	pyrrole
Hall-b (340 cm ³)		
0.8	(22,000)	Freon 11, trace of Freon 12
1.1	(40)	C ₇ alkene, C ₈ alkane, C ₈ alkene
1.4	(62)	C ₈ alkene, acetone
2.1	-	(benzene)
2.3	32 ^a	C ₉ alkane
2.8	-	trace trichloroethylene
3.5	0	(toluene)
5.2	1	ethylbenzene
5.5	12	xylene
6.4	1	xylene
7.0	-	trace limonene
7.4	2	C ₃ alkylbenzene
7.8	11 ^a	C ₃ alkylbenzene
8.6	4	C ₃ alkylbenzene
9.0	1	C ₄ alkylbenzene
9.4	1	C ₃ alkylbenzene
10.4	1	C ₄ alkylbenzene
11.8	3	dichlorobenzene
13.0	8	possible furfural and pyrrole
16.0	50	C ₁₆ alkane

^aComponent mixture present; some background contribution to total peak area.

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 26. SAMPLE IDENTIFICATION
(Pittsburgh-III Sample Set)

Location	Air volume sampled (cm ³)
Started Simultaneously:	
Bedroom	2000
Hall	2000
Living room-a	180
Living Room Series:	
Living room-b started 15 min after -a	230
Living room-c started 15 min after -b	200
Living room-d started 15 min after -c	220

TABLE 27. BEDROOM SAMPLES

Retention time (min)	Concentration estimate (10 ⁻⁹ g/l)	Mass spectral data
0.6	(77)	2-methylpropane
0.9	(1470)	C ₇ alkane
1.0	(1760)	C ₈ alkane, C ₈ alkene
1.2		
1.4		
1.7	(440)	C ₅ diene or cycloalkene
1.7	(240)	branched alkane
3.7	4	trace tetrachloroethylene, trace terpene (136 M ⁺)
4.9	3	terpene (136 M ⁺)
5.6	23	ethylbenzene
6.6	6	xylene
7.1	28	limonene
7.3	0.6	C ₃ alkylbenzene (n-propyl-)
7.5	0.3	C ₃ alkylbenzene (methylethyl- or isopropyl-)
8.4	6	C ₄ alkylbenzene
8.7	7	C ₃ alkylbenzene
9.1	0.7	C ₄ alkylbenzene
9.5	0.3	C ₄ alkylbenzene (n- or isobutyl-)
11.9	15	dichlorobenzene
12.1	8	alkane
12.9	26	pyrrole
14.1	17	C ₁₅ alkane main, methylpyrrole

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 28. SUMMARY OF RELATIVE CONCENTRATIONS
(Pittsburgh III Sample Set)

	Concentration Estimate (10^{-9} g/l)					
	Bedroom, 2000 cm ³ sample	Hall 2000 cm ³ sample	Living Room-a 180 cm ³ sample	Living room-b 230 cm ³ sample	Living room-c 200 cm ³ sample	Living room-d 220 cm ³ sample
2-methyl propane	(77)	(78)	(2280)	NA	(630)	(8)
C ₇ alkane	(1470)	(2920)	(14500)	NA	(8810)	(350)
C ₇ alkane, C ₈ alkene	(1760)	(303)		NA		(8200)
C ₈ diene or cycloalkene	(440)	(212)	(980)	NA	(750)	(806)
branched alkane	(240)	(48)				
terpene, 136 M ⁺	3	3		20	3	3
ethylbenzene	23	14		25	6	14
xylene	6	5		7	2	0.6
limonene	28	57	61	84	30	42
C ₃ alkylbenzene	0.6	0.6				
C ₃ alkylbenzene	0.3	0.6				
C ₄ alkylbenzene	6	8		8		
C ₄ alkylbenzene	7	6		11		
C ₃ alkylbenzene	0.7	0.6		0.3		
C ₄ alkylbenzene	0.3	0.3		0.1		
dichlorobenzene	15	4		7	~1	3
alkane	8	0.9		3	~1	1
pyrrole	26	8		26		
C ₁₅ alkane, methyl pyrrole	17	3		14		

() Retention volumes in the sampler are exceeded by the volume of air sampled.

TABLE 29. RETENTION VOLUMES IN
PITTSBURGH HI-RISE APARTMENT SAMPLERS
(Sample volume in cm³)

n-hexane	250
n-heptane	520
n-octane	2000
3,5-dimethylhexane	150
cyclohexane	<100
3-hexyne	900
benzene	450
toluene	1950
ethanol	150
1-propanol	650
1-butanol	2800
allyl alcohol	600
acetone	160
2-butanone	750
diacetyl	1600
isobutanal	~100
n-pentanal	>2000
diethylether	~100
p-dioxane	1500
acetic acid	500
ethylacetate	950
ethyl sulfide	1250
diethylamine	220
n-butylamine	700
acetonitrile	250
pyridine	3200
nitromethane	700
chloroform	400
trichloroethylene	1000

bedroom sample with retention time identification for comparison with the other data formats. The data from the other samples are compiled in Table 28. The small sample sizes taken (180-230 cm³) preclude obtaining much information on components at levels below 10×10^{-9} g/l, most of the ambient organics. The higher levels of release-related species are detected.

Discussion

Table 29 has been included to give an idea of specific retention volumes for a variety of chemical classes in the samplers used. If the specific retention volume for a compound is exceeded by the volume of air sampled, it is not quantitatively collected by the sampler. It can be seen that the propellants for all the sampling studies fall into this category. It was noted that the smaller samples represent a more accurate quantitative estimate of these species. Although the specific retention volume for Freon 11 has not been studied, the values obtained for Freon 11 from the small samples represent the most accurate propellant values. The propellant from the aerosol furniture polish (Pittsburgh III Set) is a mixture of at least six aliphatic hydrocarbons. The 200 cm³ samples are most likely reasonable concentration estimates. The butane propellant concentrations in the previously reported sample set are subject to greater error due to the specific retention volume effect.

Chapter 3

THE GEOMET INDOOR-OUTDOOR AIR POLLUTION MODEL NUMERICAL TECHNIQUES ON THE SENSITIVITY COEFFICIENTS*

DERIVATION OF THE GIOAP MODEL SENSITIVITY COEFFICIENTS

A sensitivity study involves analyzing the change in the output(s) of a model resulting from a change in the parameter(s). When a function such as

$$y_i = f(t_i, \bar{P}) \quad (3-1)$$

where

t_i = time, $i = 1, \dots, n$

$\bar{P} = \{p_1, \dots, p_k\}$ = vector of parameters

$\bar{P}_0 = \{p_{10}, \dots, p_{k0}\}$ = fixed value of $\bar{P}$

is to undergo a sensitivity analysis, the procedure is straightforward: evaluate the first partial derivatives of f with respect to the parameter(s) at a specified condition (i.e., $\partial f / \partial p_j | (t_i, \bar{P}_0)$, $j = 1, \dots, k$) in order to determine how variations in the parameter(s) affect the output. However, when the function is of the form

$$y_i = f(t_i, \bar{P}_i, y_{i-1}) \quad (3-2)$$

where

t_i = time, $i = 1, \dots, n$

y_0 = initial value of the output variable

$\bar{P}_i = \bar{P}(t_i) = \{p_{1i}, \dots, p_{ki}\}$, $i = 1, \dots, n$ = vector of time-dependent parameters

$\bar{P}_{i0} = \{p_{1i0}, \dots, p_{ki0}\}$ = fixed value of $\bar{P}_i$, $i = 1, \dots, n$

* Prepared by GEOMET, Incorporated - Mr. John W.C. Stark.

the analysis becomes considerably more involved. This is due to the fact that at $t = t_i$, f is not only a function of $\bar{p}_i$ but also of all the previous parameter vectors, $\bar{p}_j$, $j = 1, \dots, i-1$, and y_0 as a result of the dependence on y_{i-1} . Thus the sensitivity coefficients that must be determined are

$$\left. \frac{\partial f}{\partial y_0} \right| (t_j, \bar{p}_{j0}, y_{j-1}) \quad j = 1, \dots, n \quad (3-3)$$

and

$$\left. \frac{\partial f}{\partial p_i} \right| (t_j, \bar{p}_{j0}, y_{j-1}) \quad i = 1, \dots, k, \quad j = 1, \dots, n. \quad (3-4)$$

The sensitivity coefficients will be derived below by first obtaining a general expression for the total differential, then taking the sensitivity coefficients to be the coefficients of the parameter differentials. Before proceeding with the derivation of the sensitivity coefficients for equation (3-2), the following additional notation is required:

$d\bar{p}_i = d\bar{p}(t_i) = (dp_{1i}, \dots, dp_{ki})$, $i = 1, \dots, n$ = vector of time-dependent parameter variations

$d\bar{p}_{i0} = (dp_{1i0}, \dots, dp_{ki0})$ = fixed value of $d\bar{p}_i$, $i = 1, \dots, n$

dy_i = the change in the dependent variable at time, t_i , $i = 1, \dots, n$, due to a change in the parameter(s)

$$\frac{\partial y_i}{\partial \bar{p}_i} = \left(\left. \frac{\partial f}{\partial p_j} \right| (t_i, \bar{p}_{i0}, y_{i-1}), j = 1, \dots, k \right)$$

= the vector of partial derivatives of the function with respect to the parameter(s) evaluated at $(t_i, \bar{p}_{i0}, y_{i-1})$

$$\frac{\partial y_i}{\partial y_{i-1}} = \left. \frac{\partial f}{\partial y_{i-1}} \right| (t_i, \bar{p}_{i0}, y_{i-1})$$

$$\frac{\partial y_i}{\partial \bar{p}_i} \cdot d\bar{p}_{i0} = \sum_{j=1}^k \left(\left. \frac{\partial f}{\partial p_j} \right| (t_i, \bar{p}_{i0}, y_{i-1}) \right) dp_{ji0}$$

= the dot product of the two vectors, $\partial y_i / \partial \bar{p}_i$ and $d\bar{p}_{i0}$.

The general expression for dy_m , $1 \leq m \leq n$, is derived in the following set of equations:

$$dy_1 = \frac{\partial y_1}{\partial y_0} dy_0 + \frac{\partial y_1}{\partial \bar{P}_1} \cdot d\bar{P}_{10} \quad (3-5)$$

$$\begin{aligned} dy_2 &= \frac{\partial y_2}{\partial y_1} dy_1 + \frac{\partial y_2}{\partial \bar{P}_2} \cdot d\bar{P}_{20} = \frac{\partial y_2}{\partial y_1} \frac{\partial y_1}{\partial y_0} dy_0 \\ &+ \frac{\partial y_2}{\partial y_1} \frac{\partial y_1}{\partial \bar{P}_1} \cdot d\bar{P}_{10} + \frac{\partial y_2}{\partial \bar{P}_2} \cdot d\bar{P}_{20} \end{aligned} \quad (3-6)$$

$$\begin{aligned} dy_3 &= \frac{\partial y_3}{\partial y_2} dy_2 + \frac{\partial y_3}{\partial \bar{P}_3} \cdot d\bar{P}_{30} = \frac{\partial y_3}{\partial y_2} \frac{\partial y_2}{\partial y_1} \frac{\partial y_1}{\partial y_0} dy_0 \\ &+ \frac{\partial y_3}{\partial y_2} \frac{\partial y_2}{\partial y_1} \frac{\partial y_1}{\partial \bar{P}_1} \cdot d\bar{P}_{10} + \frac{\partial y_3}{\partial y_2} \frac{\partial y_2}{\partial \bar{P}_2} \cdot d\bar{P}_{20} + \frac{\partial y_3}{\partial \bar{P}_3} \cdot d\bar{P}_{30} \end{aligned} \quad (3-7)$$

⋮

$$\begin{aligned} dy_m &= \left(\prod_{i=1}^m \frac{\partial y_i}{\partial y_{i-1}} \right) dy_0 + \sum_{i=1}^{m-1} \left(\prod_{j=i+1}^m \frac{\partial y_j}{\partial y_{j-1}} \right) \frac{\partial y_i}{\partial \bar{P}_i} \cdot d\bar{P}_{i0} \\ &+ \frac{\partial y_m}{\partial \bar{P}_m} \cdot d\bar{P}_{m0} \end{aligned} \quad (3-8)$$

In order to obtain the coefficients of the parameter differentials, expand the dot products in equation (3-8)

$$\begin{aligned}
 dy_m = & \left(\prod_{i=1}^m \frac{\partial y_i}{\partial y_{i-1}} \right) dy_0 + \sum_{l=1}^k \sum_{i=1}^{m-1} \left(\prod_{j=i+1}^m \frac{\partial y_j}{\partial y_{j-1}} \right) \left(\frac{\partial f}{\partial p_l} \bigg| (t_i, \bar{p}_{i_0}, y_{i-1}) \right) dp_{li_0} \\
 & + \sum_{l=1}^k \left(\frac{\partial f}{\partial p_l} \bigg| (t_m, \bar{p}_{m_0}, y_{m-1}) \right) dp_{lm_0}
 \end{aligned} \quad (3-9)$$

Now the desired sensitivity coefficients may be easily obtained from equation (3-9). For a given value of m , $1 \leq m \leq n$, the sensitivity coefficients are as follows:

$$\frac{\partial f}{\partial y_0} \bigg| (t_m, \bar{p}_{m_0}, y_{m-1}) = \prod_{i=1}^m \frac{\partial y_i}{\partial y_{i-1}} \quad (3-10)$$

$$\begin{aligned}
 \frac{\partial f}{\partial p_i} \bigg| (t_m, \bar{p}_{m_0}, y_{m-1}) &= \alpha_j \left(\frac{\partial f}{\partial p_i} \bigg| (t_j, \bar{p}_{j_0}, y_{j-1}) \right) \quad i = 1, \dots, k \\
 j &= 1, \dots, n
 \end{aligned} \quad (3-11)$$

where

$$\alpha_j = \begin{cases} 1, & j = m \\ \prod_{l=j+1}^m \frac{\partial y_l}{\partial y_{l-1}}, & 1 \leq j < m \end{cases}$$

As mentioned previously, at $t = t_m$, f is a function of y_0 and $\bar{p}_i$, $i = 1, \dots, m$. Equation (3-10) illustrates this dependence on y_0 and shows how an error in y_0 is propagated throughout the time period being modeled.

Similarly, equation (3-11) for $j = 1, \dots, m-1$ illustrates the dependence of f on past parameter vectors and shows how an error in a parameter is propagated: at the time the error appears, the change in the dependent variable is due to the change in the parameter; however, at subsequent points in time, this error is manifested as a change in the dependent variable resulting from a change in the y_{j-1} term. Finally, equation (3-11) at $j = m$ shows that when an initial error occurs in a parameter, the change in the dependent variable is due only to the parameter error.

In order to apply equations (3-10) and (3-11) to the GEOMET Indoor-Outdoor Air Pollution model, let $t_i = t_f$, $t_{i-1} = t_0$, and evaluate the expressions defined by equations (4) and (16) through (22) of Section 2 at $t = t_f$. Equation (3-10), when applied to the GIOAP model at $t = t_m$, $1 \leq m \leq n$, becomes

$$\left. \frac{\partial f}{\partial C_0} \right| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = e^{-\sum_{i=1}^m (v_i + D_i)}. \quad (3-12)$$

Similarly, the following sensitivity coefficients are obtained by applying equation (3-11) at $t = t_m$ to equations (17) through (22):

$$\left. \frac{\partial f}{\partial m_i} \right| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = \alpha_i \left\{ \left(\frac{v_i}{D_i + v_i} \right) \left[\left(\frac{1}{D_i + v_i} - t_{i-1} \right) e^{-(v_i + D_i)} - \left(\frac{1}{D_i + v_i} - t_i \right) \right] \right\} \quad (3-13)$$

$$\left. \frac{\partial f}{\partial b_i} \right| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = \alpha_i \left(\frac{v_i}{D_i + v_i} \right) (1 - e^{-(v_i + D_i)}) \quad (3-14)$$

$$\frac{\partial f}{\partial S_i} \Big| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = \alpha_i \left[\frac{1 - e^{-(v_i + D_i)}}{V(v_i + D_i)} \right] \quad (3-15)$$

$$\begin{aligned} \frac{\partial f}{\partial D_i} \Big| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = & \\ & \alpha_i \left\{ \left(\frac{1}{D_i + v_i} \right)^2 \left[m_i v_i t_{i-1} + v_i b_i + \frac{S_i}{V} - \frac{2m_i v_i}{D_i + v_i} \right] e^{-(v_i + D_i)} \right. \\ & - \left[C_{i-1} - \left(\frac{1}{D_i + v_i} \right) \left(m_i v_i t_{i-1} + v_i b_i + \frac{S_i}{V} - \frac{m_i v_i}{D_i + v_i} \right) \right] e^{-(v_i + D_i)} \\ & \left. - \left(\frac{1}{D_i + v_i} \right)^2 \left(v_i b_i + \frac{S_i}{V} - \frac{2m_i v_i}{D_i + v_i} + m_i v_i t_i \right) \right\} \quad (3-16) \end{aligned}$$

$$\frac{\partial f}{\partial V} \Big| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = \alpha_i \left[\frac{S_i}{V^2(D_i + v_i)} \right] \left[e^{-(v_i + D_i)} - 1 \right] \quad (3-17)$$

$$\begin{aligned} \frac{\partial f}{\partial v_i} \Big| (t_m, m_m, b_m, S_m, D_m, V, v_m, C_{m-1}) = & \\ & \alpha_i \left\{ - \left(\frac{1}{D_i + v_i} \right)^2 \left[m_i D_i t_{i-1} + b_i D_i - \frac{S_i}{V} - m_i \left(\frac{D_i - v_i}{D_i + v_i} \right) \right] e^{-(v_i + D_i)} \right. \\ & - \left[C_{i-1} - \left(\frac{1}{D_i + v_i} \right) \left(m_i v_i t_{i-1} + b_i v_i + \frac{S_i}{V} - \frac{m_i v_i}{D_i + v_i} \right) \right] e^{-(v_i + D_i)} \\ & \left. + \left(\frac{1}{D_i + v_i} \right)^2 \left[b_i D_i - \frac{S_i}{V} - m_i \left(\frac{D_i - v_i}{D_i + v_i} \right) + m_i D_i t_i \right] \right\} \quad (3-18) \end{aligned}$$

NUMERICAL SENSITIVITY ANALYSIS EXAMPLES FOR THE GIOAP MODEL

In this chapter, three examples are presented that will illustrate the use of the sensitivity coefficients given in Section 3 of Vol. 1 of this report. The data used in these examples are taken from actual model calculations (CO data for the Baltimore Conventional House, first visit, hours 0800-1500). Table 30 gives the nominal values for all parameters used in the examples.

TABLE 30. NOMINAL CONDITIONS USED IN THE SENSITIVITY STUDY EXAMPLES

House: Baltimore Conventional (Visit #1)

Pollutant: CO

Volume: 13,575 ft³

Hour	C _{in} (ppm)	C _{out} (ppm)	S (mg/h)	ν (air exchanges/h)
0800	1.33	1.33	-	-
0900	2.23	1.33	677.77	1.20
1000	1.04	0.00	0.00	1.20
1100	0.31	0.00	0.00	1.20
1200	0.68	0.00	440.14	1.20
1300	1.02	0.00	619.13	1.20
1400	1.01	0.00	528.17	1.20
1500	0.30	0.00	0.00	1.20

The first example deals with the case in which an error is made when a parameter value is estimated initially, but, after that initial error, no other errors are introduced. This situation is most likely to arise in the estimation of the initial indoor air pollutant concentration, C_0 , because it is estimated only once, unlike some other parameters (e.g., S and ν), which must be estimated for each hour. Using Equation 23 of Vol. 1, Table 31 gives the approximate error (dC_{in}) and actual error (ΔC_{in}) for each hour due to an error in C_0 . Here it should be noted that since the GIOAP model is a linear function of C_0 , $dC_{in} = \Delta C_{in}$; however, this does not show up in some of the entries in the table due to the fact that some values were rounded off. As mentioned

in Section 3 of Vol. 1, since the sign of $\partial C_{in}/\partial C_{in0}$ is positive, a decrease (increase) in C_0 will cause a decrease (increase) in C which can be seen in Table 31. Finally, for this particular case, it is seen that by the 11th hour the effects of the error in C_0 on C are minimal.

TABLE 31. ERRORS IN C_{in} DUE TO AN ERROR IN C_{in0}

House: Baltimore Conventional (Visit #1)

Pollutant: CO

Hour	ΔC_{in0} (ppm)	$\frac{\partial C_{in}}{\partial C_{in0}}$	dC_{in} (ppm)	ΔC_{in} (ppm)
0800	-0.665	-	-	-
0900	0.000	0.3012	-0.2003	-0.20
1000	0.000	0.0907	-0.0603	-0.06
1100	0.000	0.0273	-0.0182	-0.01
1200	0.000	0.0082	-0.0055	-0.01
1300	0.000	0.0025	-0.0016	0.00
1400	0.000	0.0007	-0.0005	0.00
1500	0.000	0.0002	-0.0001	0.00

The next example deals with the case in which the parameter errors vary with time and are recurrent. This situation can occur in any number of the GIOAP parameters (e.g., m , b and v) which must be estimated. For this example the internal source rate parameter (S) was chosen and $\Delta S_i = -0.3 S_i$, $i = 9, \dots, 15$ (i.e., a negative 30% error in S). The data for this example are presented in Table 32. Here, as in the previous example, $dC_{in} = \Delta C_{in}$, because the GIOAP model is linear with respect to S . As pointed out in Section 3 of Vol. 1, the sign of $\partial C_{in}/\partial S$ is positive; thus a decrease (increase) in S results in a decrease (increase) in C_{in} . This is illustrated in Table 32. Also, the error term consists not only of the error due to the current perturbation of S but also of the error due to the past perturbations of S which are transmitted via the C_{i-1} term (see equation (5)). Notice that during hours 0900 through 1100, the situation is similar to that of the previous example (i.e., an initial error with no errors introduced subsequently) and that the

effect of the error in S has diminished by the 11th hour. However, during hours 1200 through 1400, errors in S occur each hour, so, even though the effects of previous errors in S begin to dissipate, the overall error in C_{in} is not reduced appreciably.

TABLE 32. ERRORS IN C_{in} DUE TO ERRORS IN S

House: Baltimore Conventional (Visit #1)

Pollutant: CO

Hour	ΔS (mg/h)	$\frac{\partial C_{in}}{\partial S}$ (ppm/mg/h)	$\frac{\partial C_{in}}{\partial C_{in0}}$	dC_{in}^* (ppm)	ΔC_{in} (ppm)
0800	-	-	-	-	-
0900	-203.331	0.0015	-	-0.2690	-0.27
1000	0.000	0.0015	0.3012	-0.0810	-0.08
1100	0.000	0.0015	0.3012	-0.0244	-0.02
1200	-132.042	0.0015	0.3012	-0.1820	-0.18
1300	-185.739	0.0015	0.3012	-0.3005	-0.30
1400	-158.451	0.0015	0.3012	-0.3001	-0.30
1500	0.000	0.0015	0.3012	-0.0904	-0.09

* In these tables, dC_{in} (Col. 5) was computed using the following formula:

$$dC_i = \frac{\partial C_i}{\partial C_{i-1}} dC_{i-1} + \frac{\partial C_i}{\partial S_i} dS_i, \quad i = 9, \dots, 15$$

$\downarrow$
Col. 4

$\downarrow$
Col. 5

$\downarrow$
Col. 3

$\downarrow$
Col. 2

This formula is an equivalent form of Equation (3-8). Also, it should be noted that any attempt to calculate dC_{in} from its components appears to result in an error. Actually, some of the values were obtained via computer and were rounded off when entered in the table.

The final example illustrates two cases: 1) that of a recurrent constant error, and 2) that in which the GIOAP model is not a linear function of the parameter being considered. The parameter being dealt with here is the air exchange rate (ν). Table 33 presents the data associated with this example. In this example, as opposed to the previous one, the error ($\Delta \nu = 0.20$) occurs every hour, thus the error induced in C_{in} does not have a chance

to dissipate. Also, this case gives an idea of how well dC_{in} approximates ΔC_{in} when the model is not linear in the parameter being studied. Here, the approximation is fair since dC_{in} , in most cases, agrees with ΔC_{in} , in the first decimal place. Ideally, Δv should be small enough so that the GIOAP model is approximately linear in the Δv -neighborhood about the nominal point. This is illustrated by Figure 75 which shows how, for $y = f(x)$, $\Delta y = f(x+\Delta x) - f(x)$ differs from the approximation of Δy , $\Delta_a y$, found using the formula $\Delta_a y = f'(x)\Delta x$. In this case, if Δv were much larger, the validity of using dC_{in} to approximate ΔC_{in} would be questionable. Finally, in this case, $\partial C_{in}/\partial v$ is negative, which means that a decrease (increase) in v results in an increase (decrease) in C_{in} . This is intuitively plausible; however, due to the complexity of $\partial C_{in}/\partial v$, it is not possible to say that this is always the case.

TABLE 33. ERRORS IN C_{in} DUE TO ERRORS IN v

House: Baltimore Conventional (Visit #1)
Pollutant: CO

Hour	Δv (air exchanges/h)	$\frac{\partial C_{in}}{\partial v}$ (ppm/air exchanges/h)	$\frac{\partial C_{in}}{\partial C_{in0}}$	dC_{in}^* (ppm)	ΔC_{in} (ppm)
0800	-	-	-	-	-
0900	-0.20	-0.3608	-	0.0722	0.07
1000	-0.20	-0.5827	0.3012	0.1382	0.16
1100	-0.20	-0.3132	0.3012	0.1043	0.13
1200	-0.20	-0.3277	0.3012	0.0969	0.11
1300	-0.20	-0.5344	0.3012	0.1361	0.16
1400	-0.20	-0.5884	0.3012	0.1587	0.18
1500	-0.20	-0.3042	0.3012	0.1086	0.14

* In these tables, dC_{in} (Col. 5) was computed using the following formula

$$dC_i = \frac{\partial C_i}{\partial C_{i-1}} dC_{i-1} + \frac{\partial C_i}{\partial v_i} dv_i, \quad i = 9, \dots, 15$$

$\downarrow \quad \quad \downarrow \quad \quad \downarrow$
 Col. 4 Col. 5 Col. 2
 $\downarrow \quad \quad \downarrow$
 Col. 3

This formula is an equivalent form of Equation (3-8). Also, it should be noted that any attempt to calculate dC_{in} from its components appears to result in an error. Actually, some of the values were obtained via computer and were rounded off when entered in the table.

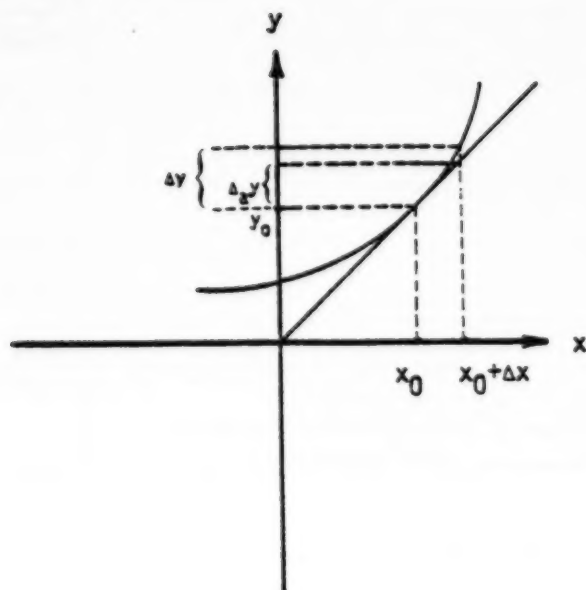


Figure 75. Graph showing how Δy differs from $\Delta_x y$ (the approximation to Δy computed as $\Delta_x y = f'(x_0)\Delta x$).